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ST. CROIX RIVER SHORELINE STUDIES 1995 -2000

MINNESOTA - WISCONSIN BOUNDARY AREA COMMISSION

MINNESOTA DEPARTMENT OF NATURAL RESOURCES

NATIONAL PARK SERVICE

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WASHINGTON COUNTY SWCD

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St. Croix River Shoreline Studies

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St. Croix River Shoreline Studies

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EXECUTIVE SUMMARY

BRIEF DESCRIPTION OF THE LOWER RIVERWAY

The Lower St. Croix National Scenic Riverway is a narrow corridor that runs for 52 miles along the boundary of Minnesota and Wisconsin, from St. Croix Falls/Taylors Falls to the confluence with the Mississippi River at Prescott/Point Douglas. Although the riverway has a natural appearance for long stretches, much of the riverway is adjacent to the rapidly growing Twin Cities metropolitan area. The St. Croix passes through various landscapes - from a deep, narrow gorge with basalt cliffs to expansive views of a wide river valley - and includes diverse biological communities. The riverway's scenery, plentiful fish and wildlife, largely unpolluted, free-flowing character, numerous access points, and closeness to the Twin Cities attract many people in the late spring, summer, and fall. Users participate in a wide range of recreational activities in the lower riverway, including motor boating, sailing, canoeing, swimming, camping, picnicking, birdwatching, fishing, and hunting.

The upper St. Croix and Namekagon Rivers above Taylors Falls were designated as a national scenic riverway in 1968. In 1972 Congress added the Lower St. Croix River to the national wild and scenic rivers system. The law requires that the lower 25 miles of the lower riverway (referred to as the state-administered zone) be administered by the states of Minnesota and Wisconsin, and that planning for the riverway be conducted jointly by the states and the secretary of the interior.

The riverway is an extremely popular recreational boating area. A key management issue facing the Lower St. Croix Management Commission is regulating boating to ensure safe, enjoyable experiences and resource protection. State-imposed water surface use regulations have been in place since 1977 to restrict boat speeds and behavior in congested areas. The management commission conducts regular surveys of boating density and has established policy that the need for regulation should be studied when density reaches 15 acres of water per moving boat in any particular area, and regulations should be imposed when density reaches 10 acres of water per moving boat.

The five-mile reach of river between the north city limits of Stillwater and the Arcola Sandbar (a shallow area that largely prevents boat movement farther north) is very popular with recreational boaters. It provides a highly scenic area flanked with steep cliffs. A braided channel with publicly owned islands provides a popular area for boat-related island camping. Concern has grown in recent years about boat congestion in the area and about island and shoreline erosion. Following a number of public meetings, citizens asked the natural resource agencies to conduct necessary research to determine the cause of island and shoreline erosion. The outcome of that request is the research described in this report.

RECREATIONAL BOAT USE AND DISTRIBUTION

Recreational boat distribution was captured on photographic film from an aircraft flying over the St. Croix River. The developed films were interpreted for the number and types of watercraft. That information was compiled and analyzed relative to river use and day of the week. Flight days and

starting times for 8-12 fly-overs were randomized to gain an unbiased estimate of recreational boating abundance and beach use.

In 1999, 8.5 percent of total boating use of the 52-mile riverway occurred in the study area. Boating research shows somewhat more than half of all boats engaged in recreational activities on the riverway at any time are moving, while the remainder are beached on public or private shorelines. In 1999, 6.7 percent of all moving craft on the riverway were in the study area, while 11.4 percent of all beached craft in the riverway were in the study area.

In the study area in 1999, density was 11.2 acres of water per moving craft. Boating densities in the study area have fluctuated during study years and have ranged between 7.5 and 12.5 acres of water per moving craft. Overall boating use of the riverway increased steadily through the 1960s, 1970s and early 1980s, but remained fairly stable from the mid-1980s to early-1990s. In 1993, flood conditions lasted through much of the summer and boating activity was reduced. Since 1993, the number of boats on the St. Croix has increased. The number of cruisers appear to be increasing more rapidly than the number of fishing boats and runabouts.

GEOMORPHIC CHANGES IN THE ST. CROIX RIVER ISLANDS FROM 1969 to 1991

Changes in forest structure can be used as indicators of longer-term trends in island geomorphology. This report examines changes that have occurred between 1969 and 1991 in the forest area on the islands of the St. Croix River north of the Boomsite at Stillwater, Minnesota. Reconnaissance of aerial photographs flown between the Boomsite near Stillwater and the Soo Line Swing-bridge at a scale of 1:12,000 was used to differentiate water and herbaceous vegetation from forest vegetation on islands in the study area for 1969 and 1991. Polygons of forest vegetation in the study area were digitized into an Arc-info™ geographic information system (GIS) database. The polygons were linked spatially with specific islands as defined on 7-1/2 minute USGS Topographic Quadrangles of the Riverway. The forest polygons were stratified on the basis of two criteria: a) their location relative to the Arcola Sandbar (i.e., above or below the Sandbar); and b) the relationship of their area relative to the median area of all forest polygons within the respective location zones. Changes in forest polygon area were tabulated based on location relative to the Sandbar as well as relative to median area of forest polygons. These results were also displayed in map format.

Between 1969 and 1991, the forested portions of the islands below the Arcola Sandbar have become increasingly smaller and more fragmented while those above the Sandbar have become larger and more concentrated

QUALITATIVE SHORELINE EROSION ASSESSMENT

Two trained professionals conducted a qualitative assessment of the island and mainland shorelines in a 4.5 mile stretch of the Lower St. Croix National Scenic Riverway. The study zone extended from the Boomsite Marina to the Soo Line Railroad High Bridge. The observers had a combined experience of more than thirty–five years working with erosion issues and used their professional judgement in evaluating the shorelines. The assessment used descriptive criteria; no field

measurements were taken. Shorelines were classified using the following descriptive criteria: low erosion, moderate erosion, high erosion, bedrock low erosion and shallow soils over bedrock moderate erosion. Additional observations were noted and all shorelines were photographed.

The shoreline classifications and descriptions were entered into a Geographical Information System (GIS) map layer. From the GIS, it was determined that nearly 25 percent of the islands and shorelines in the study area were in a moderate to high erosion class. However, the majority of the shorelines associated with the main navigational channel were in the moderate to high erosion class. Maps showing the erosion classification and shoreline descriptions were developed.

QUANTITATIVE SHORELINE SURVEYS

Fourteen survey sites between the DNR Boomsite boat landing (on the down-river side of the study area) and the railroad high bridge (on the upriver side of the study area) were surveyed twice each year from 1995 to 2000. The shoreline profile at each survey site was measured to a depth of approximately three feet. Shoreline profiles at all sites were compiled and analyzed using a computer spreadsheet. Successive surveys were overlaid graphically to reveal changes between the summer 1995 and fall 2000.

Over six successive boating seasons, eleven sites experienced net erosion and three sites experienced net deposition. When sorted by impact category, those sites with boat waves and/or foot traffic trampling experienced net erosion of the shoreline. Those sites with no boat waves and no foot traffic trampling experienced net deposition of material. The surveys suggested that foot-traffic trampling and boat waves are major contributing influences to shoreline erosion in the study area.

CONTROLLED RECREATIONAL BOAT WAVE GENERATION

A recreational boat was used to generate incrementally higher maximum wave heights with successive controlled runs. At each location, sediment traps, an ISCO water sampler and erosion pins were used to quantify the amount of sediment mobilized. At one site a Hydrolab water quality meter was used to measure turbidity. All sampling devices were located in approximately 1 foot of water depth. Gages were installed at each site to measure maximum wave heights. Data were collected from a total of 23 controlled runs at three sites within the study area. The data from all runs were summarized and entered into a computer spreadsheet for analysis.

The results from all four measurement techniques used in this study suggested a positive relationship between sediment mobilization and maximum wave height. In addition, the sediment trap results indicate a maximum wave height of 0.4 feet as the erosive energy threshold for beach and nearshore sands on the St. Croix River. Controlled run boat speeds less than 5 miles per hour generated maximum wave heights below the erosive energy threshold. High turbidity values were not sustained after passage of the wave train. Most redeposition occurs in the nearshore area because of the quick settling time of the sand size sediments.

NORMAL BOATING ACTIVITY EFFECTS

In the summer of 1995, investigations were initiated to better understand the effects of recreational boating on shoreline sediment erosion, resuspension, and deposition. Automatic samplers were programed to collect water samples in 10 minute intervals on off-peak (light boating activity) and peak (intense and sustained boating activity) days at nine individual locations. Composite water samples were measured for turbidity. A select number of composite samples, representing a range of turbidity values, were tested for total suspended solids (TSS) and Chlorophyl *a*. While turbidity values remained relatively low throughout all sampling periods, there was a slight increase in turbidity observed on peak boating days.

Erosion pins were placed landward and waterward perpendicular to the waterline, and changes in the surface profile were measured at the end of the day. Significant changes in the beach and nearshore surface were detected, but the findings were confounded by constant reworking of the beach and nearshore sediments by waves and changing water levels throughout the day.

In the summer of 1998, additional investigations of off-peak and peak boating days included the measurement of maximum wave heights, number and type of boats, shoreline sediment mobilization (erosion and resuspension), and deposition. The study results confirmed the 0.4 foot sediment mobilization threshold identified in the controlled run studies. The more boat waves 0.4 feet and higher in a 30 minute monitoring period, the greater the amount of sediment mobilized and redeposited in the sediment traps. Likewise, the larger the maximum wave height in a 30 minute monitoring period, the greater the amount of sediment mobilized and redeposited. Of all the boat types recorded, runabouts and cruisers had the highest correlation to the measured maximum wave heights, amount of sediment mobilized, and number of waves greater than the sediment mobilization threshold.

WIND-GENERATED WAVE EFFECTS

Wind-generated waves, wind speed, wind direction, and amount of sediment mobilized were measured at 40 stratified, randomly selected (SRS) locations. The results of the analysis suggested that the St. Croix River study reach is partially sheltered from most winds. An analysis of historic wind data showed that on the monitoring day, winds were greater than average and from a direction for the largest possible wind fetches. Duration analysis suggested wind speeds measured on monitoring day were faster than wind speeds during 90% of the year. All wind-generated wave heights were less than the 0.4-foot mobilization threshold identified in the controlled run studies. Only very small amounts of sediment were mobilized at locations with measurable wind waves. An empirical equation calculated that wind speeds of the magnitude necessary to generate 0.4-foot wind waves rarely occur in the study reach.

NORMAL AND FLOOD FLOW VELOCITY EFFECTS

Channel bottom and vertical flow velocity profiles were developed over a range of flow conditions at the fixed survey sites in the study area. Most nearshore channel bottom velocities were below the critical velocity necessary to entrain and move the mean shoreline particle size. Vertical velocity

profiles measured approximately 20 feet from the waterline indicate higher velocities in the water column than those measured at the channel bottom and nearshore.

At 40 stratified, randomly selected (SRS) locations, advective flow velocities were measured and sediment traps were used to collect samples under normal flow conditions. Only very small amounts of sediment were collected in sediment traps.

An Acoustic Doppler Flow Meter (ADFM) was used to compare normal and flood-flow velocities in the river channel. Flood flow velocities were generally a bit higher than normal flow velocities and more often greater than the critical velocity for the shoreline mean particle size.

Contributing influences to shoreline erosion operate at different temporal and spatial scales and may only be expressed in connection with other factors or events. Additional contributing factors, such as the density and distribution of shoreline vegetation, geomorphic position, sediment particle size, sediment bulk density, and recreational boat waves, all have the capacity to influence how much shoreline erosion is observed following a particular flood event. In short, shoreline erosion that is perceived to be attributable to flooding, may be due to a combination of contributing influences working at different spatial and temporal scales.

SHORELINE VEGETATION SURVEYS

Island vegetation was studied in 1996, 1997 and 1998. In 1996, vegetation measurements and species identification were completed along transects at the 14 quantitative fixed survey sites. In 1997, vegetation survey transects were completed at 40 stratified, randomly selected locations. Site selection stratification was based on boat and foot traffic absence/presence. In 1998, 60 sites were selected using stratified random methods and GIS technology from a possible 750 grid cells with boat and beach use level data. Both in 1997 and 1998, vegetation transects measured the amount of bare soil as measured from the waterline at normal summer pool elevation.

Boat use and foot traffic at the St. Croix River Islands may be negatively impacting the island vegetation and increasing the amount of bare soil. The evidence for this impact is the increase in bare soil and decrease in vegetation with higher levels of usage. This makes the islands more prone to erosion and the river more likely to move sediment downstream and negatively impact aquatic habitat. Islands without any evidence of boat or trampling use have the highest coverage of perennial vegetation and the lowest amount of bare soil.

Islands that have both boat use and trampling have the highest level of bare soil and the lowest coverage of perennial vegetation. The impact to the vegetation is felt further inland as the usage of the islands increases.

CONCLUSIONS AND FOLLOW-UP ACTION

While natural forces continue to shape the islands and shorelines of the Lower St. Croix, human induced impacts are causing the loss of vegetative ground cover, the erosion of shorelines and islands and the loss of trees. To protect the islands and shorelines from further deterioration, management actions such as lower boat speeds and closure of damaged sites may be required. The information in this study will provide the basis for those management actions.

This report does not signify the conclusion of this study. The fixed survey sites will continue to be surveyed. It is hoped that this report will encourage additional research from agencies with and without ties to the St. Croix. Readers of this report with an interest in studying the islands and shorelines of the lower St. Croix are encouraged to contact one of the participants in this initial study.

Acknowledgments

A very high level of inter-governmental cooperation was required to successfully complete this phase of the St. Croix River Shoreline Studies. The following agency staff, interns and volunteers contributed to field data collection, data analysis and report writing.

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Volunteers

Joleen Bourdaghs	Field data collection and piloting of boat.
John and Colleen Bourdaghs	Use of pontoon boat for surveys and field data collection.
Jyneen Thatcher	Field data collection.

A special thanks to the late Floyd Sherrard of Sherrard's Marina for his guidance and inspiration.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 1

INTRODUCTION

Steve Johnson and Molly Shodeen
Minnesota Department of Natural Resources
Division of Waters

May 4, 1999

The Lower St. Croix National Scenic Riverway was designated a part of the National Wild and Scenic Rivers System in 1972 by Congress, which specified that it be jointly managed by the National Park Service and the states of Minnesota and Wisconsin. The two state legislatures concurred in 1973. The National Park Service and the two state departments of natural resources created the Lower St. Croix Management Commission to cooperatively manage the riverway.

The riverway is an extremely popular recreational boating area and a key management issue facing the Lower St. Croix Management Commission is regulating boating to ensure safe, enjoyable experiences and resource protection. State-imposed water surface use regulations have been in place since 1977 to restrict boat speeds and certain activities in congested areas. The management commission conducts regular surveys of boating density and has established policy that the need for regulation should be studied when density reaches 15 acres of water per moving boat in any particular area, and regulations should be imposed when density reaches 10 acres of water per moving boat.

The five-mile reach of river between the north city limits of Stillwater and the Arcola Sandbar (a shallow area that largely prevents boat movement further north) is very popular with recreational boaters. It provides a highly scenic area flanked with cliffs, and with a braided channel and publicly owned islands it provides a popular area for boat-related island camping.

Since 1977, waterskiing has been prohibited in this area on summer weekend afternoons. Boating density in recent years has fluctuated between 7.5 and 12.5 acres of water per moving craft. Concern has grown in recent years about boat congestion in the area and about island and shoreline erosion. In 1993, the management commission began considering additional boating regulations in this area; by early 1994, it was prepared to recommend the area be designated no-wake, the most restrictive speed regulation found on the river. The management commission held a public workshop on the concept on March 23, 1994, anticipating as many as 100 people might attend; actual attendance was probably in excess of the 254 people who registered. The concept was so controversial that a new organization, the St. Croix Waterway Association, was formed to advocate for boater rights. Commentary at that meeting suggested that island erosion was caused by wind action or flooding, and not necessarily by boat wakes; citizens asked the agencies to conduct necessary research to determine the cause of island and shoreline erosion.

The outcome of that request is the research, conducted with extremely limited funds, that is described in this report.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 2

RECREATIONAL BOAT USE

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November 30, 2000

INTRODUCTION

The Lower St. Croix National Scenic Riverway is heavily used by recreational boaters due to its proximity to a large metropolitan area, its stable water levels that provide adequate depth for even very large watercraft in its lower 30 miles, its scenic character, and its excellent water quality for body-contact recreation.

The five-mile reach of the study area is among the more popular areas of the riverway for watercraft-related recreation (Figure 1). The 25 miles to the south is lake-like, with adequate depth and area for all types of craft, but is exposed to wind fetch if the winds are from the south (prevailing winds in summer are generally from the south), leading some boaters to seek more secluded waters. North of the five-mile reach of the study area, the Arcola Sandbar provides a very shallow barrier to watercraft during normal river levels. The study area is the only section of the riverway that is regularly accessible to all types of motorized watercraft that contains a braided channel, many publicly owned islands and sandbars, and scenic cliffs flanking the river on either side. The area is scenic, has many places for boaters to beach, and is protected from the wind. This leads to fairly heavy use by recreational boaters.

METHODS

The general approach of this study was to capture the distribution of recreational boats on photographic film from an aircraft flying over the St. Croix River. The developed films generated during these flights were interpreted for watercraft types and that information was compiled and analyzed relative to river use and types of days. Flight days and starting times for 8-12 fly-overs were randomized to gain an unbiased estimate of recreational boating abundance and beach use.

FINDINGS

In 1999, 8.5 percent of total boating use of the 52-mile riverway occurred in the study area (St. Mary's University, 1999a). Boating research shows somewhat more than half of all boats engaged in recreational activities on the riverway at any time are moving, while the remainder are beached on public or private shorelines. In 1999, 6.7 percent of all moving craft on the riverway were in the study area, while 11.4 percent of all beached craft in the riverway were in the study area.

Density of moving boats is an important determinant of need for management actions to regulate boating behavior, the Lower St. Croix Management Commission has determined. Current policy states studies should be initiated to determine management intervention needs when density reaches 15 acres of water surface per moving craft, and management actions should be implemented when density reaches 10 acres of water per moving craft (Lower St. Croix Management Commission, 1978). In the study area in 1999, density was 11.2 acres per moving craft. Density in the study area

has fluctuated during study years between 7.5 and 12.5. The following table shows distribution in the study years since 1983:

Year	Acres
1983	8.0
1985	10.4
1987	8.0
1989	9.2
1991	7.5
1993	12.5
1995	10.1
1997	12.4
1999	11.2

The potential for impacting shorelines varies with watercraft type, as discussed elsewhere in this report. The following table shows the percent distribution in the study area of various types of watercraft in 1997 (Macbeth, pers. comm.):

Type	Moving	Beached	Total
Canoe	1.4	0.2	0.7
Fishing	24.3	11.0	16.1
Runabout	22.5	22.3	22.4
Cruiser	29.0	23.2	25.4
Pontoon	10.5	4.1	6.5
Houseboat	4.3	30.2	20.3
Sailboat	0	0	0
PWC*	5.8	2.0	3.5
Other	2.2	7.0	5.1

*Personal watercraft

Overall boating use of the riverway increased steadily through the 1960s, 1970s and early 1980s, but remained fairly stable from the mid-1980s to early-1990s (Corps, 1998). In 1993, flood conditions lasted through much of the summer and boating activity was greatly reduced (figure 2). Since 1993, the number of boats on the St. Croix has increased (St. Mary's University, 1999b). The number of cruisers appear to be increasing more rapidly than the number of fishing boats and runabouts.

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St. Mary's University of Minnesota - Resource Studies Center. 1999b. An Analysis of Weekend Counts of Fishing Boats, Runabouts, and Cruisers on Selected Portions of the St. Croix River, 1989-1999. 8 pages.

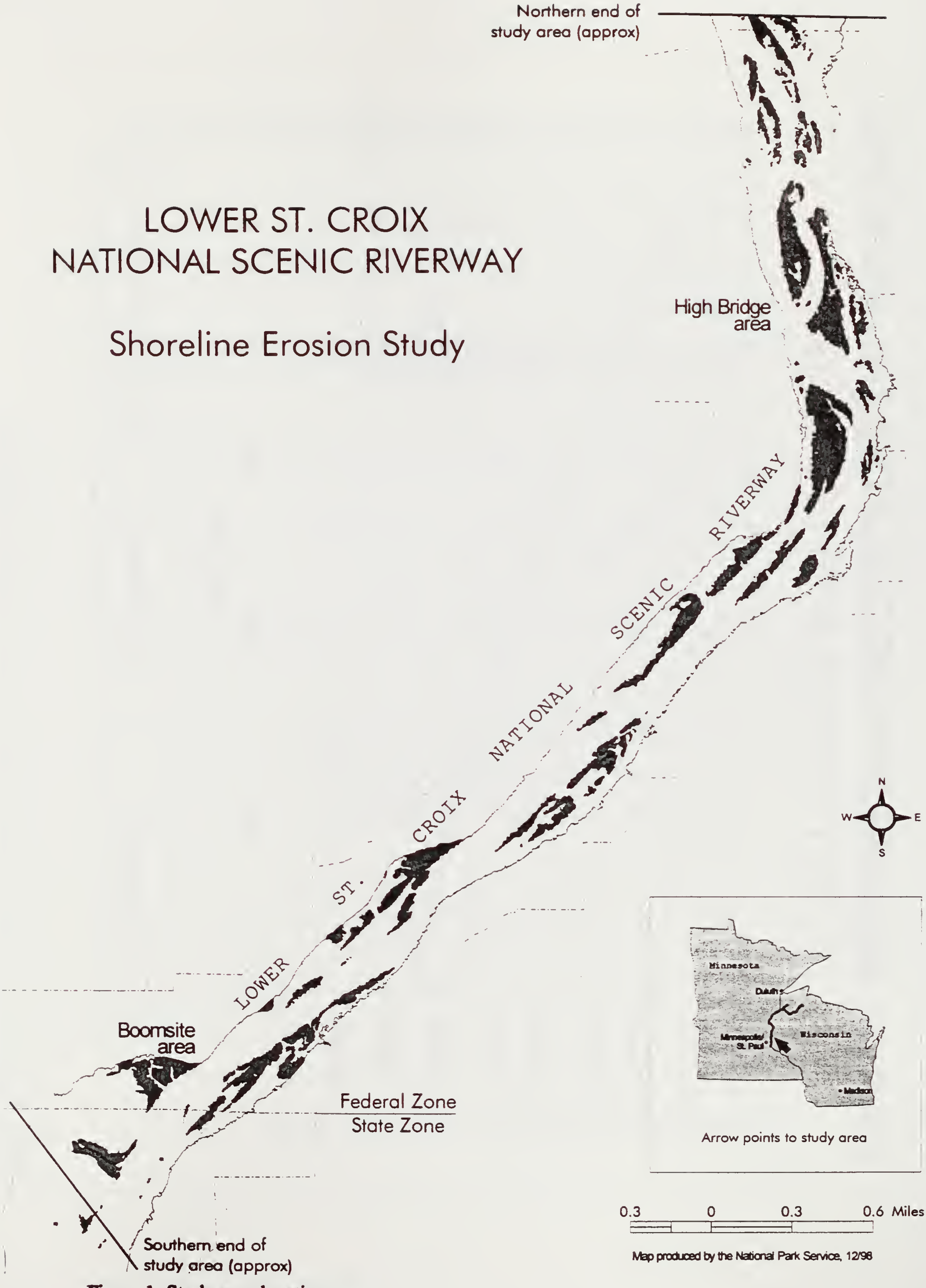

Figure 1. Study area location map.

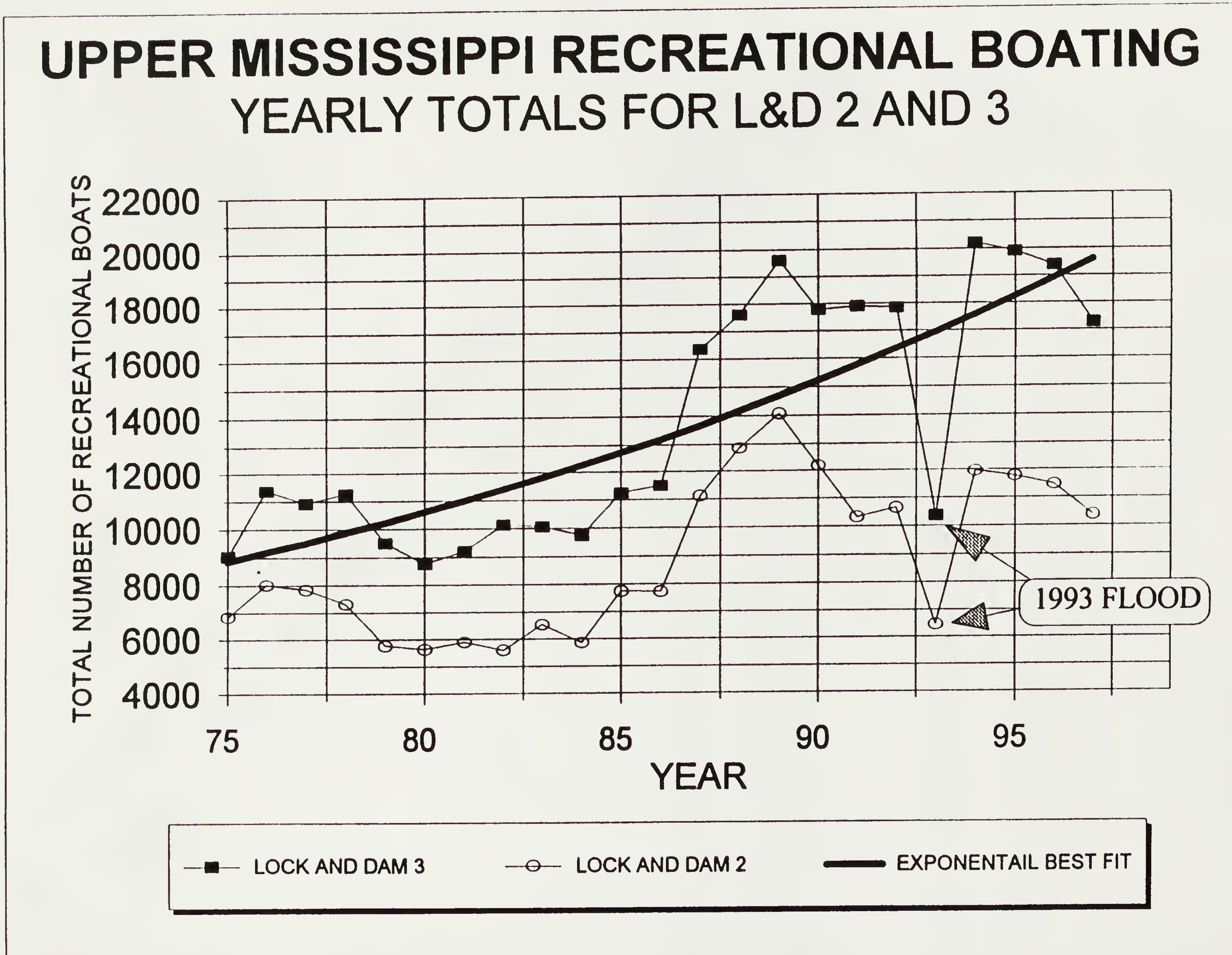

Figure 2. Recreational craft lockages through Lock and Dams 2 and 3 on the Mississippi River above and below the mouth of the St. Croix River. Many recreational craft do not use the lock

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 3

GEOMORPHIC CHANGES IN THE ST. CROIX RIVER ISLANDS FROM 1969 to 1991

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ABSTRACT

Changes in forest structure can be used as indicators of longer-term trends in island geomorphology. This report examines changes that have occurred between 1969 and 1991 in the forest area on the islands of the St. Croix River north of the Boomsite at Stillwater, Minnesota. Reconnaissance of aerial photographs flown between the Boomsite near Stillwater and the Soo Line Swing-bridge at a scale of 1:12,000 was used to differentiate water and herbaceous vegetation from forest vegetation on islands in the study area for 1969 and 1991. Polygons of forest vegetation in the study area were digitized into an Arc-Info™ geographic information system (GIS) database. The forest polygons were stratified and changes in forest polygon area were tabulated based on location relative to the Sandbar and relative to median area of forest polygons. These results were also displayed in map format. Between 1969 and 1991, the forested portions of the islands below the Arcola Sandbar have become increasingly smaller and more fragmented while those above the Sandbar have become larger and more concentrated.

INTRODUCTION

In 1972, the US Congress designated the Lower St. Croix River, from the Northern States Power Plant (NSP) dam at St. Croix Falls to the river's confluence with the Mississippi River at Prescott, a National Scenic and Recreational Riverway, making it a part of the National Park System. The Riverway designation recognized the outstanding national significance of the river's riparian character. A recently completed study found that the diversity and quality of the Riverway's resources remains high. More than most riverine environments in the Upper Midwest, the Lower St. Croix can be characterized by its good to excellent water quality (Troelstrup, et al., 1993). The River continues to support a diverse biota that includes approximately 40 freshwater mussel species and 91 freshwater fin-fish species. The Riverway is an important corridor for migratory waterfowl movement between Canada and the Gulf of Mexico, and numerous neo-tropical migratory birds breed in the Riverway's forest interior environments (Warren et al., 1993). The Riverway contains landscapes whose scenic character continues to serve as benchmark definitions of American Picturesque values (Pitt et al., 1994). In some portions of the Riverway, the prospect of a solitary encounter with the Riverway's unique biologic diversity remains high. The Riverway is prized as a setting for recreational boating by a high percentage of Minnesota registered boat owners, whether they own and operate a canoe, a motorized craft or a sailboat (Schatz, McAvoy, Pitt and Lime, 1989).

Retention of these values requires maintenance of the island, riparian and bluffland ecosystems that comprise the Riverway landscape. The expanding Minneapolis-St. Paul Metropolitan Statistical Area, through which the river passes, and changing patterns of recreational behavior pose potential threats to these ecosystems. Increasing population creates pressure for new housing development within and adjacent to the Riverway, and it also increases the demand for transportation and other development-related infrastructure.

Increasing demand for river-oriented recreation and changing patterns of River recreational use for swimming and boating present a growing potential for degradation of river water quality as well as the integrity of island ecosystems.

The Riverway contains over 227 islands. Most of the islands are forested with bottomland species, while others contain extensive wetlands and sandbars. Collectively, the islands account for 876 of the 17,910 hectares of land within the Riverway. Over 95% of these islands are located north of Stillwater in the so-called Federal zone wherein the National Park Service has major resource management responsibility. Nearly all of the islands in the Riverway were never appropriated from the public domain. When the Riverway was designated in 1972, responsibility for the islands was transferred from the Bureau of Land Management (BLM) to the National Park Service. The Park Service subsequently purchased those islands not originally managed by the BLM.

The National Park Service permits recreational use of the islands by the public. The boating public may anchor and land their boats on islands except were the Park Service explicitly prohibits such. Similarly, boaters may camp overnight on the islands except where the Park Service explicitly prohibits such use.

Anecdotal evidence suggests that forest ecosystems on the islands are deteriorating as a result of recreational boating. The degradation appears to be more severe on islands below the Arcola Sandbar than those above the Sandbar. The Arcola Sandbar at the confluence of the St. Croix River and the Apple River in Wisconsin divides boating activity on the river into two segments. Below the Sandbar, travel speeds and the size of boat wakes vary as there are few areas that have posted speed limits and many vessels types, including runabouts and cruisers as well as fishing boats and canoes, can use this river segment. Shoals at the Sandbar prevent deeper draft vessels from traveling upstream where boating is generally confined to fishing boats, pontoon boats and canoes[1]. Speeds of travel are restricted in the upper segment by narrower and shallower channels as well as by smaller boats having lower propulsion.

OBJECTIVES AND APPROACH

This chapter reports on a survey of changes occurring in the island forest ecosystems between 1969 and 1991. The objectives of the survey were to obtain data describing the morphology of the island ecosystems in approximately 1969 and 1991, digitize these two patterns of island morphology, and examine the spatial pattern of change in island morphology between the two time periods.

DATA GATHERING AND ANALYSIS

Data describing the spatial patterns of island ecosystem change and recreational boating change were compiled through aerial photographic interpretation. Compiled data were

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[1] A launch ramp at William O ' Brien State Park allows deeper draft vessels to access the river above the Arcola Sandbar when water levels permit.

digitized into a geographic information system (GIS) software produced by the Earth Systems Research Institute (ESRI) of Redlands, California. The ESRI product known as Arc-Info™ provided the technology for compiling, processing and analyzing spatial information, while ESRI's ArcView™ product provided the technology for producing the map displays contained in the chapter. Both systems operated on a Dell Dimension XPS R400™ platform using a WindowsNT™ operating system.

At the beginning of this study, two sets of aerial photographs were available. The Minnesota-Wisconsin Boundary Area Commission (MWBAC) gathers aerial photography of the river every two years for the purposes of performing boat census counts. This photography is flown over several time periods during the boating season being canvassed at a scale of approximately 1:8000, a scale that permits interpretation of vessel type and activity. The MWBAC imagery focuses, however, on the main channels and the major use areas of the river. Some islands and water surfaces in back-slough areas, where recreational use is obstructed by shallow water or channel obstructions, are not included in this photography. While this imagery allows canvassing of boating activity in a given time period, its incomplete coverage of the river renders it inadequate as a means of canvassing island forest vegetation.

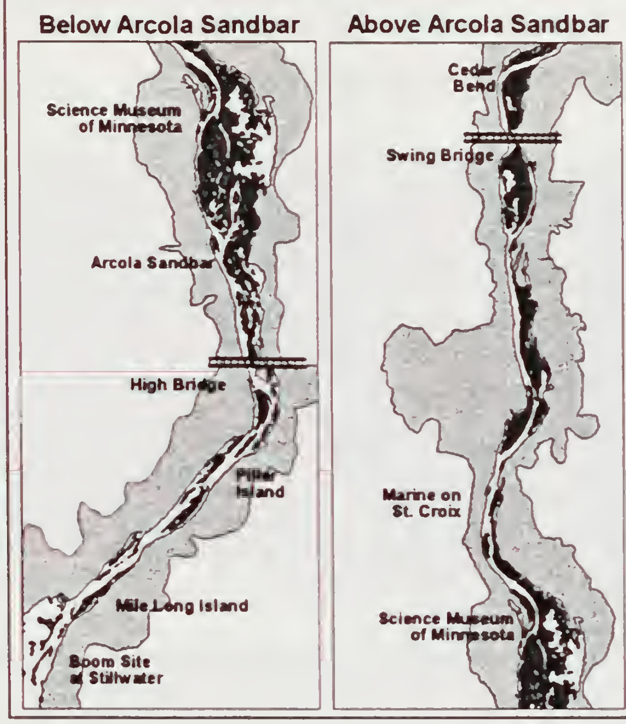
The Washington County Office of the Land Surveyor also gathers aerial photography of the river as part of a biennial fly-over of the entire county. This photography is flown on a single day during the canvassing period. It encompasses all islands in the river, so it is suitable for canvassing island ecosystem patterns at a given point in time. It is flown at a scale of approximately 1:12,000, a scale that permits interpretation of ecosystem patterns on the islands. The Washington County Office of the Land Surveyor photography was used to measure geomorphic changes in the islands between 1969 and 1991.

CHANGES IN THE MORPHOLOGY OF ISLAND ECOSYSTEMS

Island Forest Communities as Indicators of Ecosystem Structure

The islands of the St. Croix River (see Figure 1) are comprised of channel bars and point bars that have accumulated as a result of very recent geologic processes in the river. In the context of geologic time, the position and structure of the islands are constantly changing.

Figure 1. Location of Study Area Relative to Arcola Sandbar



An initial concern focuses on defining the meaning of island ecosystems in a manner that allows changes in the system to be measured and evaluated. In a riverine system where flow is constantly changing due to a regulated discharge of water from hydroelectric facilities, island shoreline is a poor indicator of ecosystem structure[2]. Similarly, herbaceous (i.e. wetland) vegetation is sometimes inundated by a variable flow regime, and its presence or absence, especially as seen from aerial photography would also be a poor choice as an indicator of ecosystem structure. Island forest vegetation, on the other hand, is generally tall enough to indicate ecosystem structure regardless of flood stage. The ability of floodplain forests to persist through a variety of flow regimes coupled with their height makes forest vegetation a more reliable indicator of island ecosystem structure.

Continued erosion of island soil eventually undermines the substrate within which trees grow. In this way, island erosion leads to decline of forest vegetation. As channel sediment accretes on islands, trees will colonize newly created island substrate that has an appropriate moisture regime for growth and development of woody vegetation. Changes in forest structure, therefore, can be used as indicators of longer-term trends in island

[2] A Northern States Power (NSP) hydroelectric plant moderates the natural flow regime of the St. Croix River at St. Croix Falls, WI . A NSP turbine just above the river's confluence with the St. Croix River moderates the flow of the Apple River.

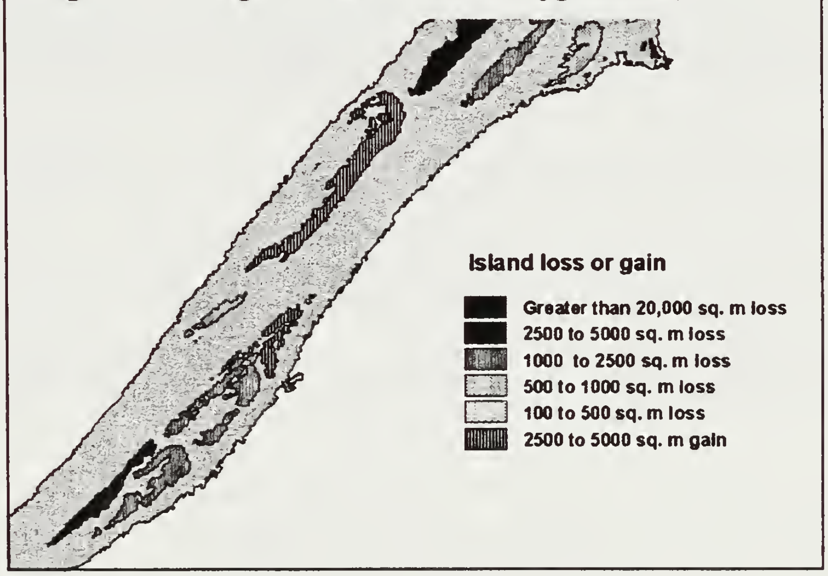
geomorphology. The presence of island forest communities at any point in time is readily detected through aerial photographic reconnaissance. Similarly, changes in island forest structure can be discerned by comparing island forest composition and dispersion at one point in time with composition and dispersion at a subsequent point in time.

Measuring Changes in Forest Area on St. Croix Islands

Reconnaissance of aerial photographs flown between the Boomsite near Stillwater and the Soo Line Swing-bridge at a scale of 1:12,000 was used to differentiate water and herbaceous vegetation from forest vegetation on islands in the study area for 1969 and 1991. Polygons of forest vegetation in the study area were digitized into an Arc-info™ geographic information system (GIS) database. The polygons were linked spatially with specific islands as defined on 7-1/2 minute USGS Topographic Quadrangles of the Riverway. The forest polygons were stratified on the basis of two criteria: a) their location relative to the Arcola Sandbar (i.e. above or below the Sandbar); and b) the relationship of their area relative to the median area of all forest polygons within the respective location zones. Changes in forest polygon area were tabulated based on location relative to the Sandbar as well as relative to median area of forest polygons. These results were also displayed in map format.

Figure 2 illustrates the nature of change in island forest polygon area that occurred between 1969 and 1991 in the vicinity of the Pillar Island. Forest polygons in this portion

Figure 2. Change in Island Forest Polygon Area, 1969-91



of the river experienced changes that resulted in both decreasing area as well as increasing area. However, as was typical of forest polygons throughout the portion of the river below the Arcola Sandbar, changes that resulted in decreasing area were more prevalent than changes that resulted in increasing area.

Figure 3 presents change in overall forest area among the St. Croix islands between 1969 and 1991. In 1969, there was significantly more total forest area on all the islands above the Arcola Sandbar than was true on all of the islands below the Sandbar. Polygons located above the Arcola Sandbar, regardless of their initial size in 1969, have gained area. Polygons located below the Sandbar have lost area.

Figure 3. Total Forest Area for St. Croix Islands, 1969-91

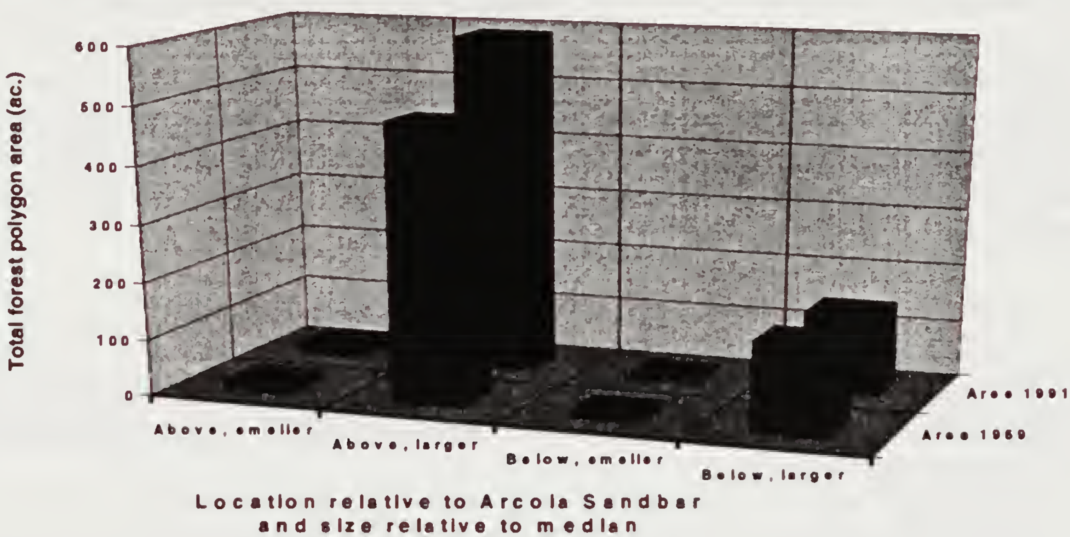
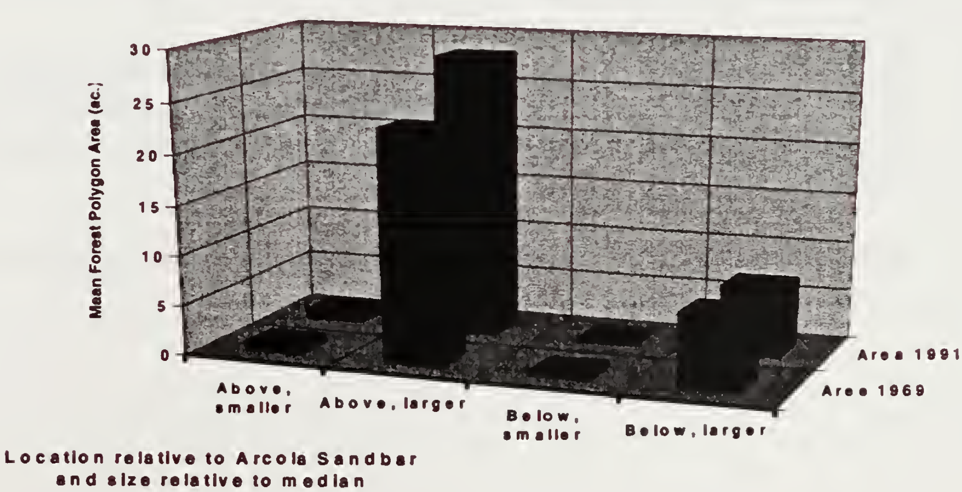


Figure 4 illustrates that mean forest polygon area on islands above the Sandbar increased between 1969 and 1991. Mean forest area on islands below the Sandbar, regardless of their initial size in 1969, has declined.

Figure 4. Mean Forest Polygon Area for St. Croix Islands, 1969-91



FINDINGS

As would be expected, strong and direct relationships exist between the change in forest area occurring in between 1969 and 1991 and the island forest area existing in 1969 as well as the island area existing in 1991. Similarly, islands in the upper 50^{th} percentile of island area in 1969 increased in area. This reconfirms the earlier finding that larger islands in 1969 throughout the river tended to gain in forest area between 1969 and 1991.

As islands gained in northerly position relative to the equator, they tended to gain additional island forest area between 1969 and 1991. Similarly, the magnitude of the increase in forest area among islands located above the Arcola Sandbar was significantly larger than the magnitude of the decrease in forest area among islands located below the Sandbar.

SUMMARY

The findings of this investigation of change in the forest ecosystems on the islands of the St. Croix River and the relationship of these changes to patterns of recreational boating can be summarized as follows:

Changes in Forest Ecosystems on the St. Croix River Islands

- Forest area on the islands above the Arcola Sandbar was larger in 1969 as well as in 1991 than was forest area on the islands below the Sandbar. Forest area on islands tended to increase in size between 1969 and 1991 with movement upstream.

- Total forest area on the islands above the Sandbar, especially on the larger islands, increased in size between 1969 and 1991, while total forest area below the Sandbar decreased in size.

- The number of forest polygons on islands below the Sandbar increased between 1969 and 1991 while mean area of these polygons decreased. In contrast, the number of forest polygons above the Sandbar decreased and their mean area increased.

- Between 1969 and 1991, forest polygons having larger area in 1969 increased in size while smaller polygons decreased in size.

CONCLUSIONS AND MANAGEMENT IMPLICATIONS

The forest polygons on the St. Croix Islands located below the Arcola Sandbar are becoming increasingly fragmented. As compared with conditions in 1969, by 1991, there were more forest polygons and they each tended to contain a smaller area. Overall, this pattern of fragmentation has reduced the total amount of forest area on islands located below the Sandbar. In contrast, the islands above the Sandbar appear to be gaining in total forest area, and the number of forest polygons appears to be declining. The pattern of island forest change above the Sandbar appears to be one of agglomeration. Furthermore, the islands most likely to experience a declining area of forest between 1969 and 1991 were those with smaller areas in 1969. In general, smaller islands below the Arcola Sandbar were most likely to experience declining forest area between 1969 and 1991.

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ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 4

QUALITATIVE ASSESSMENT OF THE EROSION CONDITION OF THE ISLANDS AND SHORELINE OF THE ST. CROIX RIVER ABOVE STILLWATER, MINNESOTA

Randy Ferrin[1], and Wendy Griffin[2]
Maps by Diane Whited[3] and Marianna Young[1]

1-National Park Service, St. Croix National Scenic Riverway
2-Washington Soil and Water Conservation District
3-University of Minnesota (formerly of the NPS)

August 27, 1998

ABSTRACT

In 1996, an assessment was made of the erosion condition of the islands and shorelines of the Lower St. Croix River above Stillwater, Minnesota. This evaluation was conducted as part of a larger interagency study to determine the effects of boat waves, human foot-traffic, camping, and natural forces on the stability of the islands and shorelines. The assessment used descriptive criteria; no field measurements were taken. The descriptions were entered into a geographical information system map layer. From the GIS, it was determined that nearly twenty-five percent of the islands and shorelines in the study area were in a moderate to high erosion class. However, the majority of the shoreline associated with the main navigational channel was in the moderate to high erosion class. Maps showing the erosion potential and on-site conditions were developed.

METHODS

Two observers conducted a qualitative assessment of the erosion potential and condition of the islands and shorelines in a 4.5 mile stretch of the Lower St. Croix National Scenic Riverway. The study zone extended from the Boomsite Marina to the Soo Line Railroad High Bridge and is the same study zone as a larger interagency study of recreational impacts on the islands. The observers had a combined experience of over thirty–five years working with erosion issues and used their professional judgement in evaluating the condition of the islands and shoreline. No on-site measurements were taken. Shoreline (which will be used to indicate both island and mainland shoreline) was evaluated using the following descriptive criteria.

> Low erosion: well vegetated with both groundcover and overhead canopy, gently sloped, with little or no evidence of erosion.
> Moderate erosion: gently to moderately sloped, some bare soil, some roots exposed, and evidence of erosion.
> High erosion: steep slope or cut bank, exposed tree root wads, little or no ground cover, bare soil, evidence of recent erosion.

Two additional categories were developed for shoreline which had bedrock or shallow soils over bedrock.

> Bedrock: exposed bedrock with no soils or vegetation-low erosion.
> Shallow soils over bedrock: some vegetation on shallow soils-moderate erosion.

The observation platform was a pontoon boat which could maneuver close to shore and in shallow backwaters. A detailed base map developed from 1991 air photos of the study area was used to record the observed conditions. Each category had a corresponding color code and as the shoreline was evaluated it was coded on the base map at the

appropriate location. Other observations were hand written on the map, such as "dead canopy" or "leaning trees". See maps 1 through 6.

The assessment was conducted on September 5, 1996 when the water level at the Stillwater staff gage was 675.45 feet. The normal summer pool is 675.0 feet. The water level allowed the observers to see any undercut banks or undercut root systems.

After the evaluation was completed, the observations were entered into a geographical information system (GIS) database. This allowed the production of detailed maps depicting the erosion class for the entire study area, along with a verbal description of the shoreline condition. On June 9-10, 1998, these maps were checked on the river at random locations to determine if the original assessment was correct and if the transfer to the GIS had been done accurately. No adjustments were required.

RESULTS AND DISCUSSION

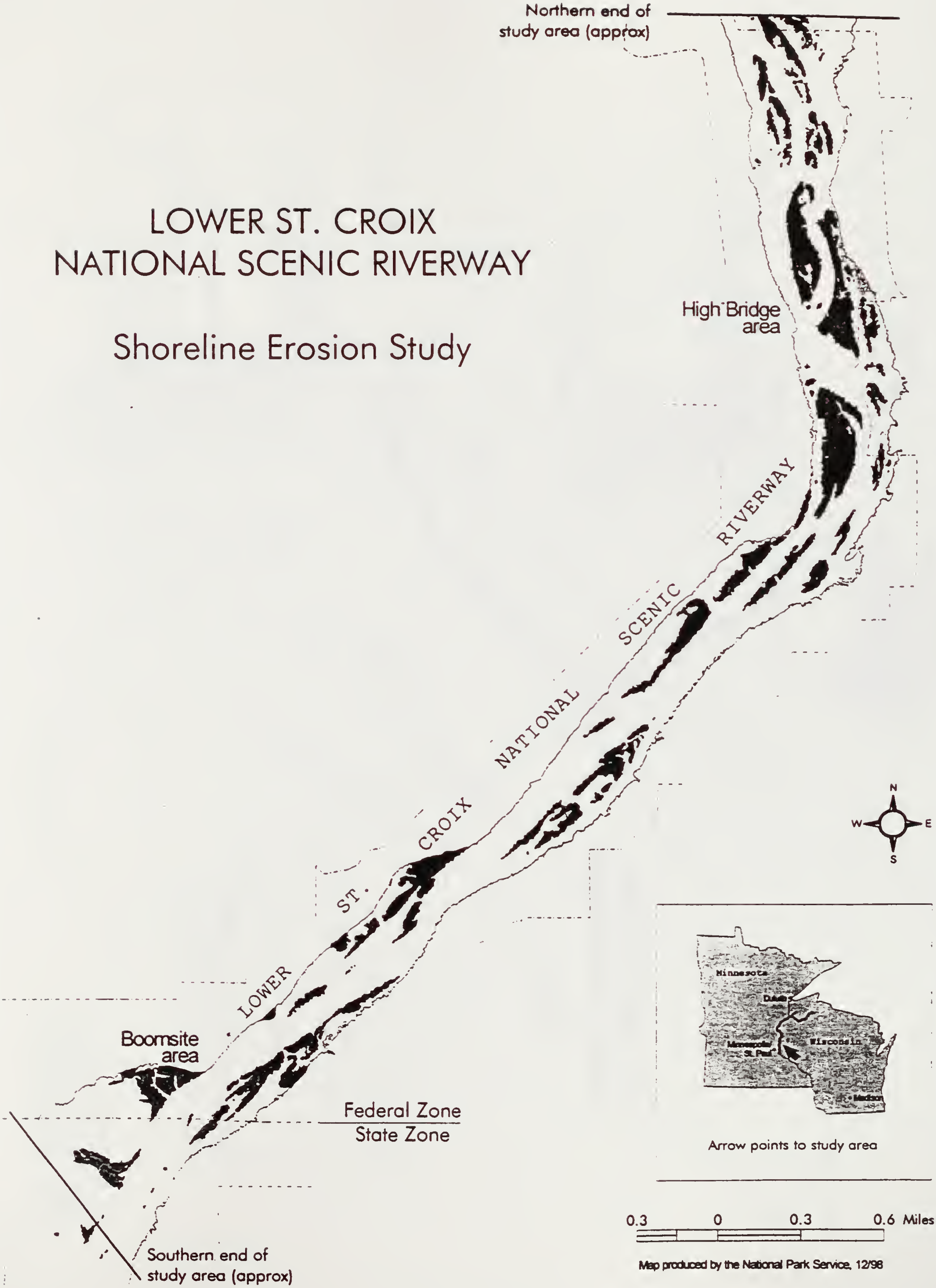
The results of the assessment are the six maps which follow. These provide a snapshot of the erosion condition of the shoreline in a 4.5-mile stretch of the Lower St. Croix River as of 1996-1998. The maps begin at the southern (downstream) end of the study reach. North is at the top of each map and the river is flowing towards the bottom of each map. Because of the length of the study reach and the level of detail, the study was broken into six maps, with slight overlap on each map. A match line is included to show how each map relates to adjoining maps. The distance scale varies slightly between maps to insure maximum detail within the format of an 8.5 inch by 11 inch page.

Using the GIS software ArcView^{tm}, version 3.0, the total length of shoreline in each category was calculated. There are some limitations to the preciseness of this exercise, but the results depict the relative amount of each category. The percentages do not equal 100 percent due to rounding.

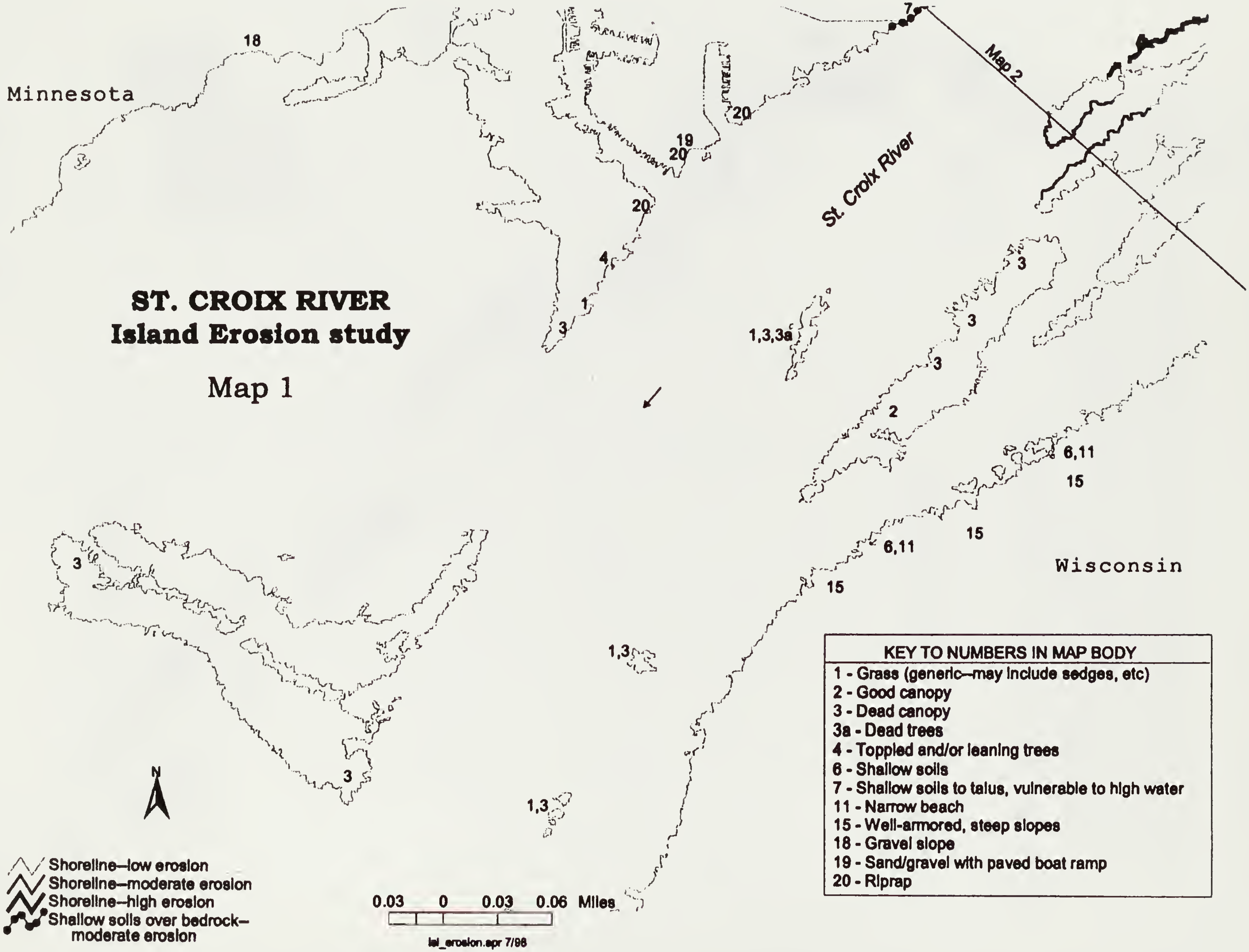
Shoreline Type	Total Length in feet	Percent of total
Low erosion	186, 965	68.3%
Bedrock-low erosion	20,360	7.4%
Moderate erosion	30,770	11.2%
High erosion	20,635	7.5%
Shallow soils over bedrock -moderate	15,015	5.5%
Total shoreline	273,745	

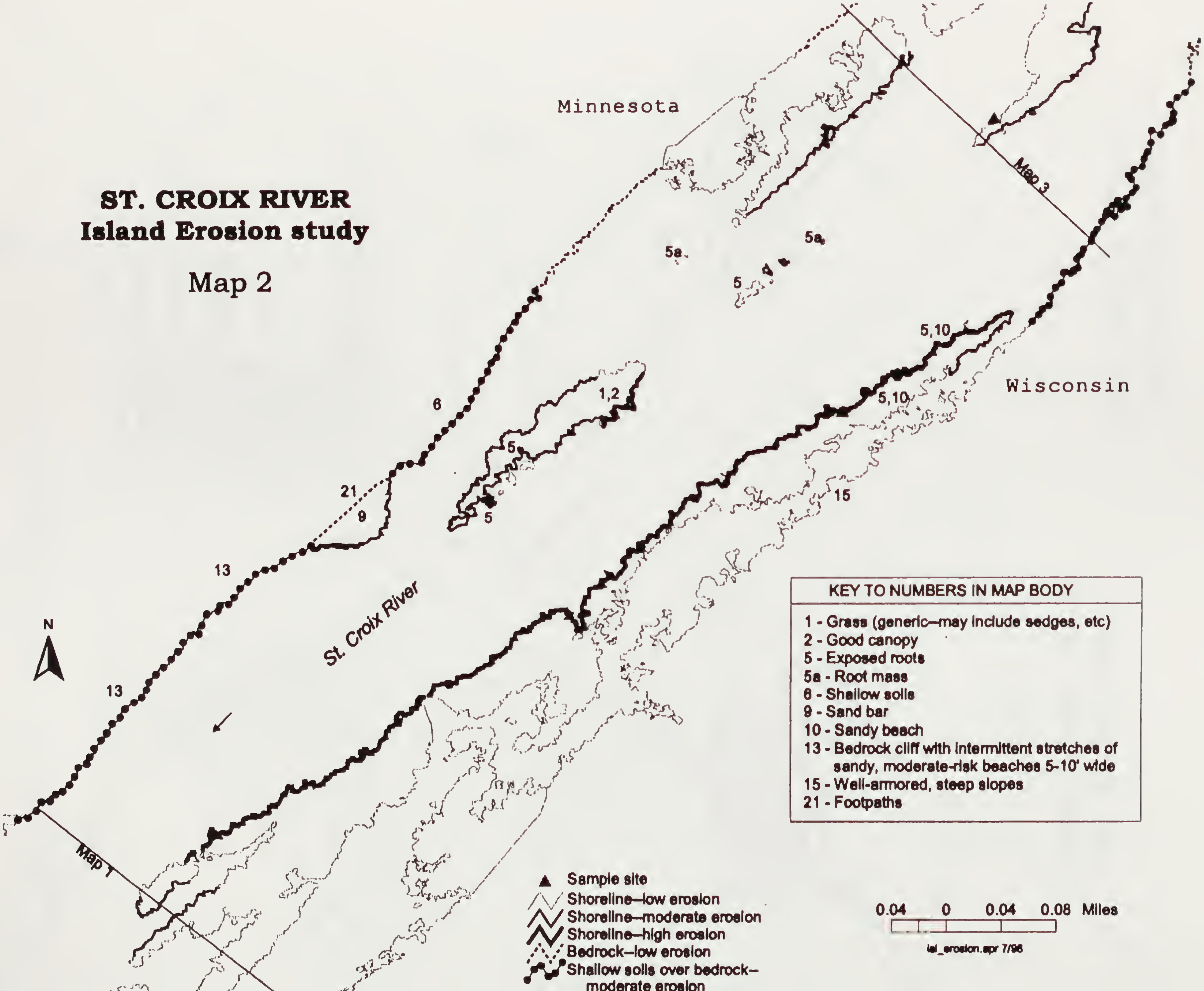
Nearly twenty-five percent of the shoreline in the 4.5-mile study area was in the moderate to high erosion categories. Conversely, seventy-five percent was in the low erosion

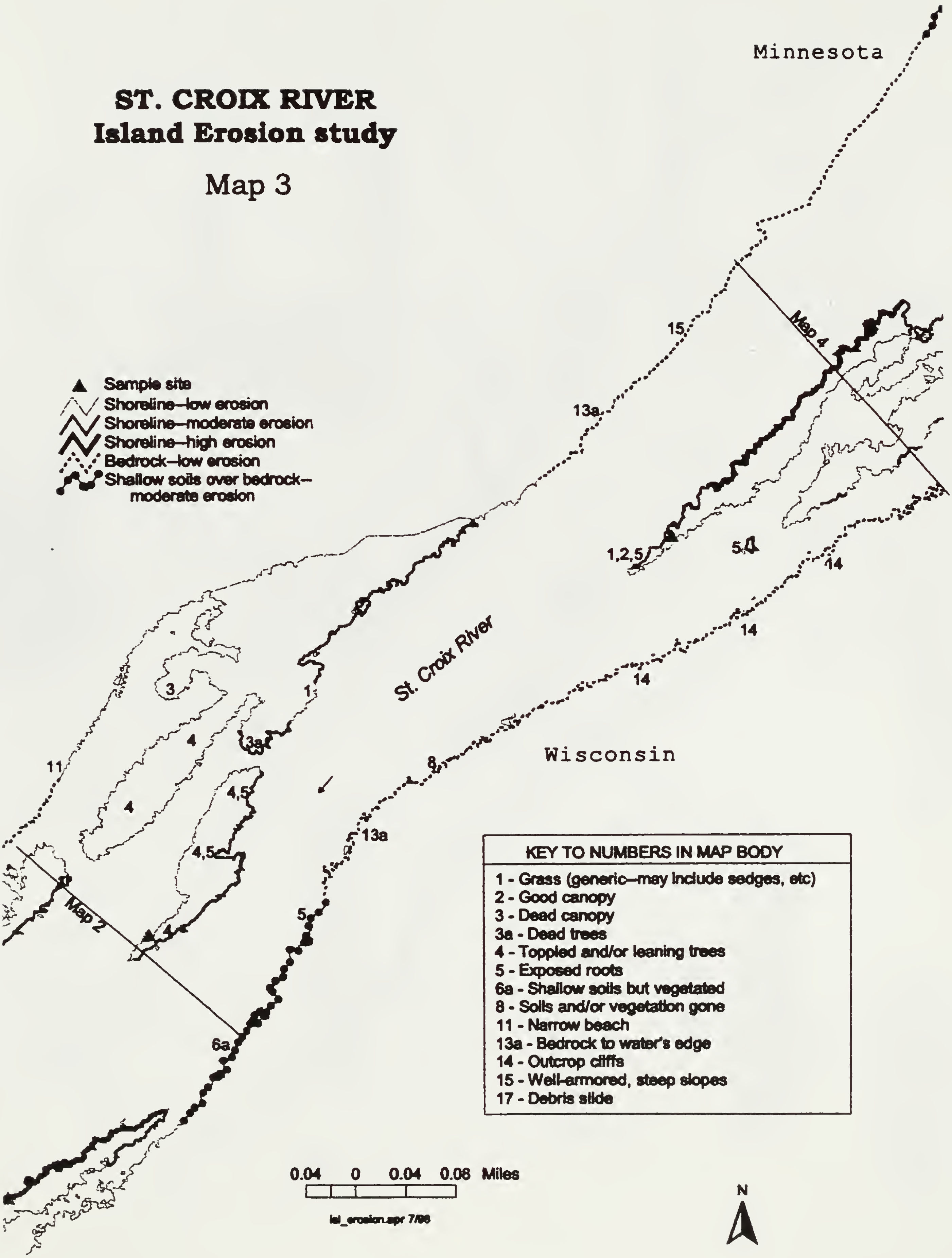
category. Qualitatively, the majority of the shoreline associated with the main navigation channel was in the moderate to high erosion class, while most of the shoreline classified as low erosion was located away from the main navigational channel. See Figure 2 in Chapter 5 for a map of the primary navigational channel. The reason for these conditions is the subject of other chapters in this interagency report.



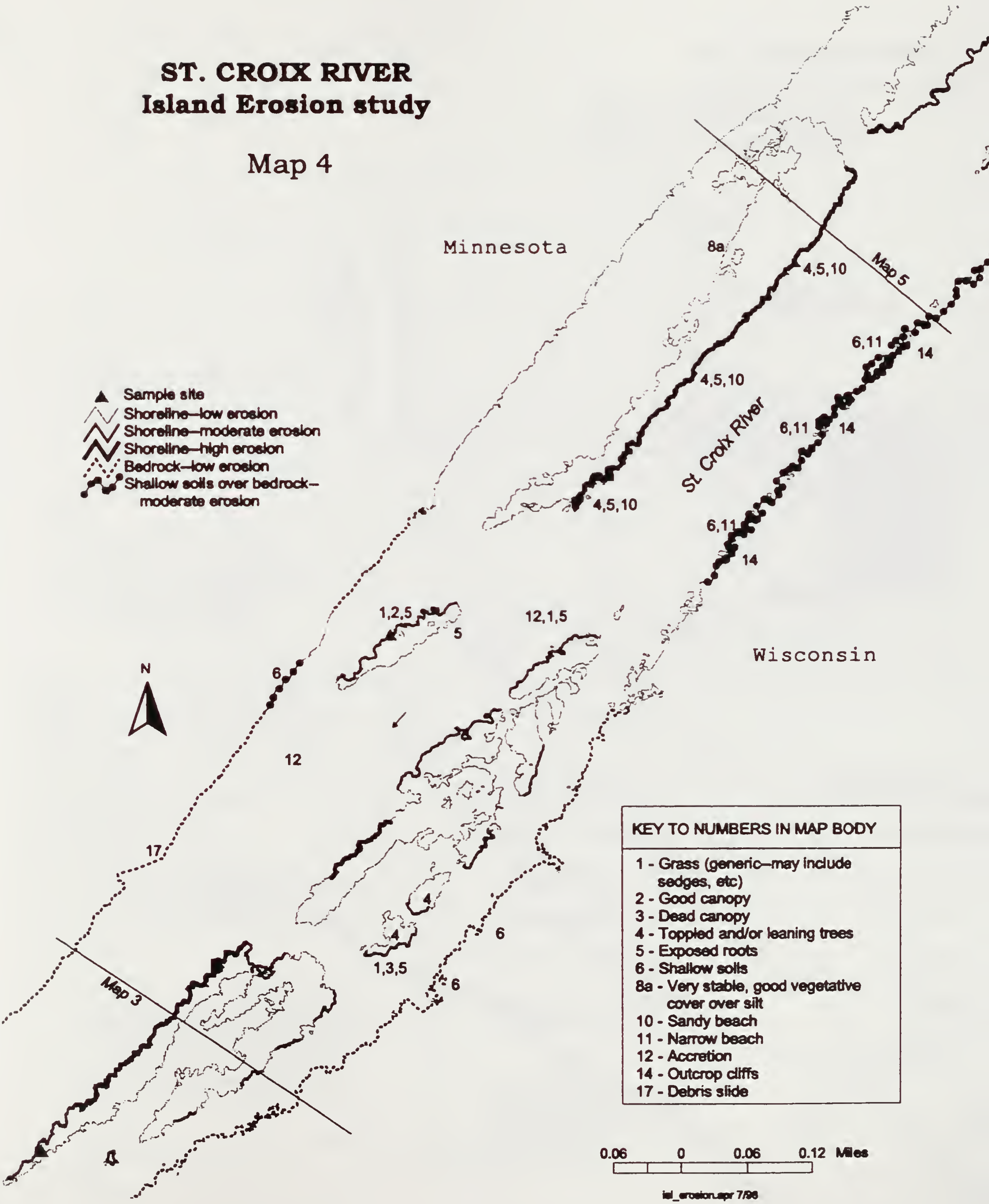
Chapter 4, Figure 1


ST. CROIX RIVER
Island Erosion study
Map 1
Minnesota
Wisconsin
St. Croix River
Map 2
18
20
19
20
20
4
1
3
7
1,3,3a
3
3
3
2
6,11
15
15
6,11
15
1,3
1,3
3
3
N
KEY TO NUMBERS IN MAP BODY
1 - Grass (generic--may include sedges, etc)
2 - Good canopy
3 - Dead canopy
3a - Dead trees
4 - Toppled and/or leaning trees
6 - Shallow soils
7 - Shallow soils to talus, vulnerable to high water
11 - Narrow beach
15 - Well-armored, steep slopes
18 - Gravel slope
19 - Sand/gravel with paved boat ramp
20 - Riprap
Shoreline--low erosion
Shoreline--moderate erosion
Shoreline--high erosion
Shallow soils over bedrock--moderate erosion
0.03 0 0.03 0.06 Miles
isl_erosion.apr 7/98


ST. CROIX RIVER
Island Erosion study
Map 2
Minnesota
Wisconsin
St. Croix River
Map 1
Map 3
N
6
13
13
21
9
5
5
1,2
5a
5a
5
5,10
5,10
15
KEY TO NUMBERS IN MAP BODY
1 - Grass (generic--may include sedges, etc)
2 - Good canopy
5 - Exposed roots
5a - Root mass
6 - Shallow soils
9 - Sand bar
10 - Sandy beach
13 - Bedrock cliff with intermittent stretches of sandy, moderate-risk beaches 5-10' wide
15 - Well-armored, steep slopes
21 - Footpaths
Sample site
Shoreline--low erosion
Shoreline--moderate erosion
Shoreline--high erosion
Bedrock--low erosion
Shallow soils over bedrock--moderate erosion
0.04 0 0.04 0.08 Miles
isl_erosion.apr 7/96

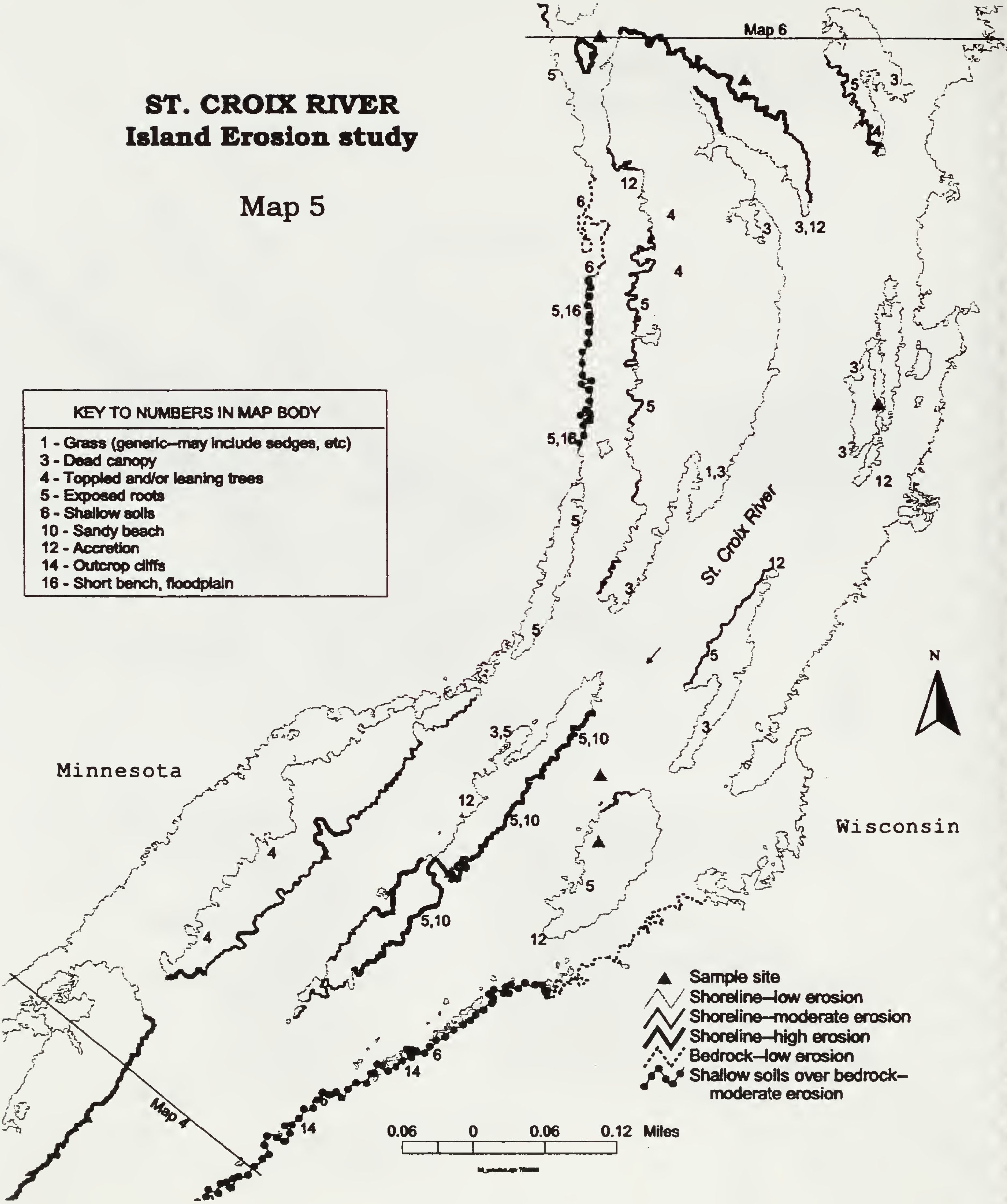


ST. CROIX RIVER
Island Erosion study
Map 3
Minnesota
Wisconsin
St. Croix River
Map 4
Map 2
Sample site
Shoreline--low erosion
Shoreline--moderate erosion
Shoreline--high erosion
Bedrock--low erosion
Shallow soils over bedrock--moderate erosion
15
13a
1,2,5
5,1
14
14
14
3
1
4
3a
11
8
4,5
4
4,5
13a
4
5
6a
KEY TO NUMBERS IN MAP BODY
1 - Grass (generic--may include sedges, etc)
2 - Good canopy
3 - Dead canopy
3a - Dead trees
4 - Toppled and/or leaning trees
5 - Exposed roots
6a - Shallow soils but vegetated
8 - Soils and/or vegetation gone
11 - Narrow beach
13a - Bedrock to water's edge
14 - Outcrop cliffs
15 - Well-armored, steep slopes
17 - Debris slide
0.04 0 0.04 0.08 Miles
N


ST. CROIX RIVER
Island Erosion study
Map 4
Minnesota
Wisconsin
St. Croix River
Map 5
Map 3
N
Sample site
Shoreline—low erosion
Shoreline—moderate erosion
Shoreline—high erosion
Bedrock—low erosion
Shallow soils over bedrock—moderate erosion
8a
4,5,10
4,5,10
4,5,10
6,11
14
6,11
14
6,11
14
1,2,5
5
12,1,5
6
12
17
4
4
1,3,5
6
6
KEY TO NUMBERS IN MAP BODY
1 - Grass (generic—may include sedges, etc)
2 - Good canopy
3 - Dead canopy
4 - Toppled and/or leaning trees
5 - Exposed roots
6 - Shallow soils
8a - Very stable, good vegetative cover over silt
10 - Sandy beach
11 - Narrow beach
12 - Accretion
14 - Outcrop cliffs
17 - Debris slide
0.06
0
0.06
0.12
Miles
isl_erosion.apr 7/98

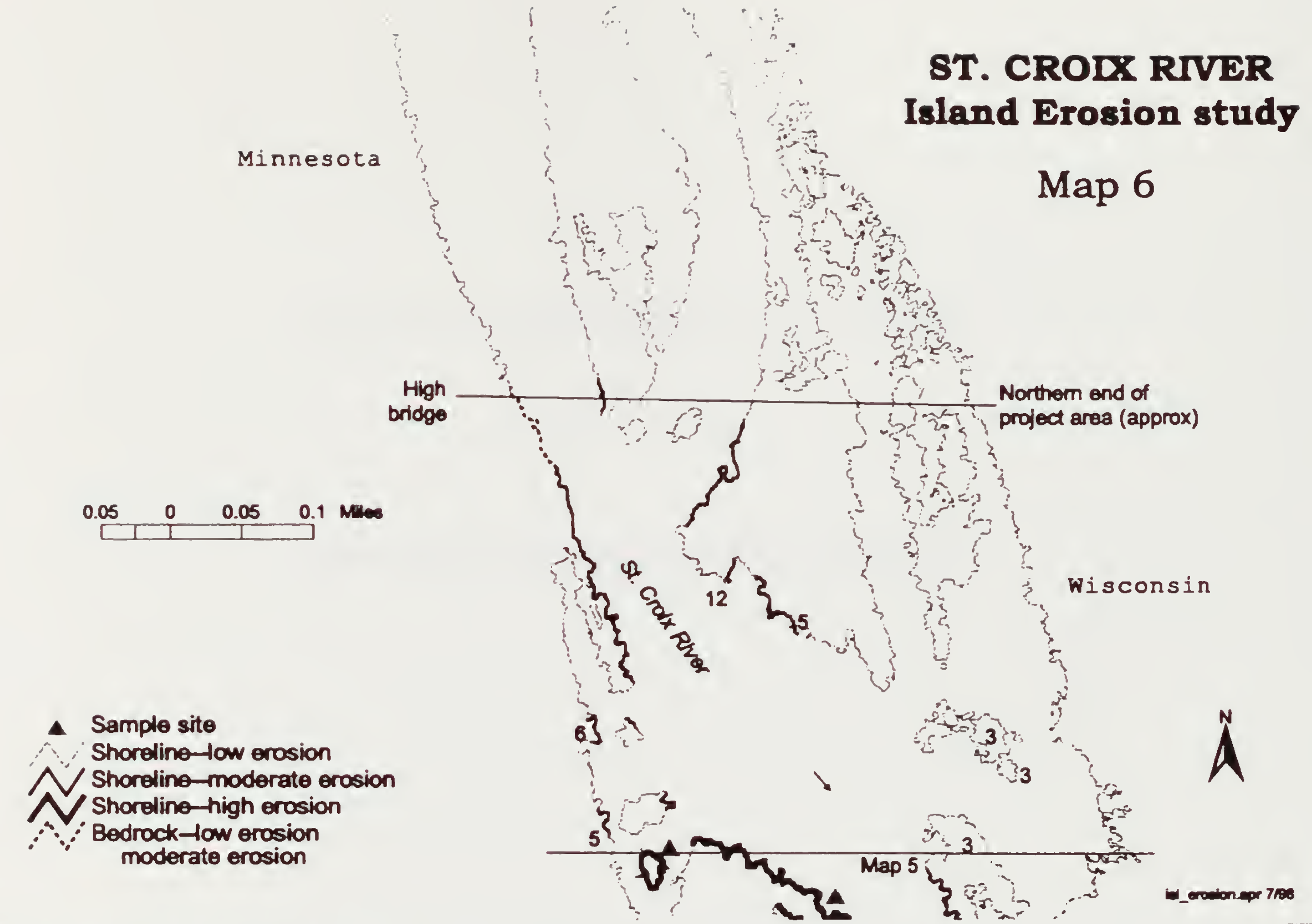
ST. CROIX RIVER
Island Erosion study

Map 5



ST. CROIX RIVER
Island Erosion study

Map 6



KEY TO NUMBERS IN MAPS 1-6
1 - Grass (generic--may include sedges, etc)
2 - Good canopy
3 - Dead canopy
3a - Dead trees
4 - Toppled and/or leaning trees
5 - Exposed roots
5a - Root mass
6 - Shallow soils
6a - Shallow soils but vegetated
7 - Shallow soils to talus, vulnerable to high water
8 - Soils and/or vegetation gone
8a - Very stable, good vegetative cover over silt
9 - Sand bar
10 - Sandy beach
11 - Narrow beach
12 - Accretion
13 - Bedrock cliff with intermittent stretches of sandy, moderate-risk beaches 5-10' wide
13a - Bedrock to water's edge
14 - Outcrop cliffs
15 - Well-armored, steep slopes
16 - Short bench, floodplain
17 - Debris slide
18 - Gravel slope
19 - Sand/gravel with paved boat ramp
20 - Riprap
21 - Footpaths

SHORELINE TYPE	LENGTH (in feet)*
Shoreline - low erosion	186,965 (68%)
Shoreline - moderate erosion	30,770 (11%)
Shoreline - high erosion	20,635 (7%)
Bedrock - low erosion	20,360 (7%)
Shallow soils over bedrock - moderate erosion	15,015 (5%)
TOTAL	273,745

*Lengths calculated only within boundaries of project area; percentages do not equal 100% due to rounding

ST. CROIX RIVER SHORELINE STUDIES

CHAPTER 5

QUANTITATIVE SHORELINE SURVEYS

Wendy Griffin
Washington County Soil and Water Conservation District

Dan Kalmon
Washington County Soil and Water Conservation District

Scot Johnson
Minnesota Department of Natural Resources
Division of Waters

November 15, 2000

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ABSTRACT

Quantitative shoreline surveys over six successive boating seasons documented net shoreline erosion at 11 of 14 sites. The data suggest that foot traffic and boat waves contributed to this erosion.

INTRODUCTION AND PURPOSE OF STUDY

The Water Resources Management Plan for the St. Croix River Basin (January 20, 1995) formed a Recreational Impacts Subcommittee to study a selected list of recreational issues. The issues included the relative impacts of land-based uses, boat wakes, wind waves and river currents on soil erosion and sediment resuspension. These investigations are a collaborative interagency effort designed to provide scientific documentation of conditions specific to the St. Croix River. Shoreline surveys were initiated during the 1995 boating season in an attempt to document the impacts listed above and their combined seasonal effects on St. Croix River shorelines.

METHODS

Site Selection

The study area was a 3.8-mile stretch of river from the railroad high bridge (river mile 28.6) downstream to the Department of Natural Resources Boomsite boat landing (river mile 24.8). This area of the lower St. Croix is abundant with islands and back channels, lending itself to a wide spectrum of recreational use.

Fourteen survey sites between the railroad high bridge (on the up-river side of the study area) and the DNR Boomsite boat landing (on the down-river side of the study area) were surveyed appoximately twice each year from 1995 to 2000 (figures 1 and 2). The shoreline profile of each site was surveyed to a depth of approximately 3 feet. Shoreline profiles at all sites were compiled in a computer spreadsheet. Successive surveys were overlaid graphically to reveal profile changes between the summer 1995 and fall 2000.

Members of the study team selected the fourteen fixed survey sites according to one of the following four impact categories: 1) *No foot-traffic trampling and no recreational boat waves - 3 sites ; 2) *No foot-traffic trampling with recreational boat waves - 4 sites ; 3) *Foot-traffic trampling with no recreational boat waves - 4 sites and 4) *Both foot-traffic trampling and recreational boat waves - 3 sites. Impact categories were defined to help the team observe resource impacts throughout the range of low to high recreational use and differentiate contributing influences to shoreline erosion. Historical river use and professional judgment were used along with a site selection matrix to choose the fixed survey sites. The team was guided through the site selection zone by the late Floyd Sherrard, who supplied the team with valuable historical and current knowledge of recreational river use.

Establishment of Survey Sites

The following methods were used to establish permanent survey transects:

1. A piece of rerod was driven into the ground approximately 30 feet from the shoreline and an automatic level was set up directly overhead (point zero). The horizontal scale was oriented to north using a compass and the point zero location was tied into nearby landmarks by compass bearings. Detailed location records were made in field notebook for future reference.
2. A vertical datum with an assumed elevation of 100 feet was established by driving a lag bolt into a large nearby tree. The lag bolt was marked with flagging.
3. A horizontal control was established by driving a second piece of rerod approximately 4 feet landward from point zero and perpendicular to flow to provide a consistent line of sight for all future surveys. Both rerod markers were driven completely into the ground to discourage tampering by island users.

Survey Protocol

The following protocol was used for data collection at each survey transect site:

1. Located the vertical benchmark and approximate location of point zero.
2. Located actual rerod locations using a metal detector and shovel.
3. Identified point zero.
4. Set up automatic level and recorded vertical bench mark reading.
5. Flagged "point zero" and second rerod to establish "line of sight".
6. Stretched the measuring tape along "line of sight" to a depth of 3' of water (or 25' waterward of waterline if < 3' of water exists) and secured the tape to a temporary stake in the channel.
7. Recorded survey rod heights along tape beginning at point zero ground elevation and at two foot intervals waterward.
8. Noted water's edge.
9. Closed survey with a measurement back to the vertical bench mark.

FINDINGS

Survey data were graphed to compare changes in shoreline profiles over time (figures 3-18). Changes due to erosion and deposition were documented at all fourteen sites. At some of the sites there was not a clear progression of continued erosion but rather a series of erosion events followed by some deposition and then more erosion. Table 2 was developed to track changes in shoreline processes over time and to summarize the **net** change at all sites as of October 2000. Changes in shoreline profiles ranged from five feet of deposition to nine feet of erosion (measured horizontally). A select number of sites were graphed to illustrate the net change from the first survey to the last survey (figures 4, 6, 9, 12, 14, 16, and18).

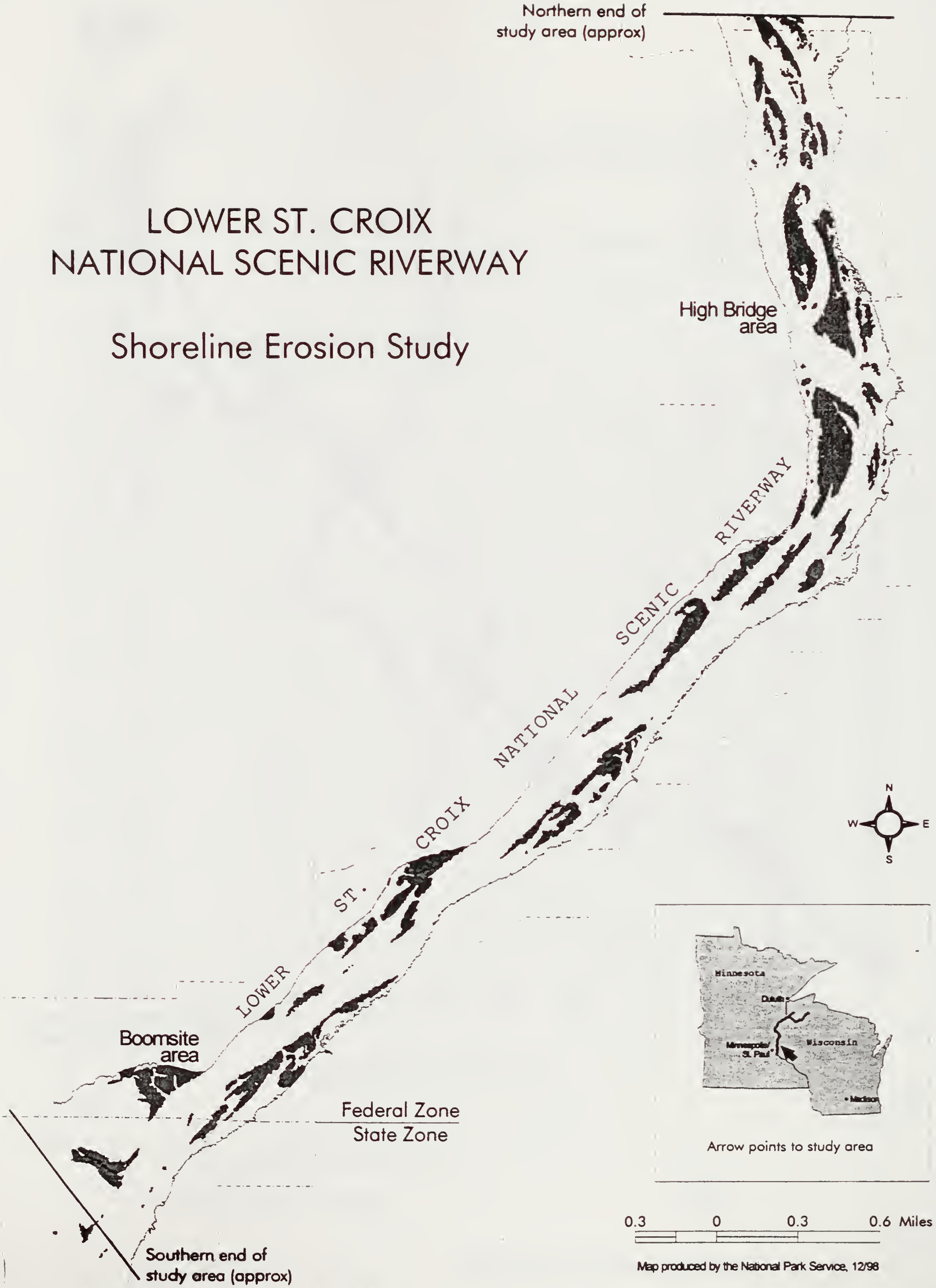
DISCUSSION AND CONCLUSIONS

Over the course of six successive boating seasons, shoreline profile surveys demonstrated that eleven sites had net erosion and three sites had net deposition. However, review of the profiles at the Sites 1A and 1B suggested forces other than river advective flow, wind waves, or boat waves may be at work on this island. The 1995 Site 1A profile reveals a steep scarp face suggesting that accelerated erosion was occurring prior to 1995. Profiles from 2000 suggested continued erosion at Site 1A and deposition at Site 1B. Therefore, for our impact analysis we will not include Sites 1A and 1B.

When sorted by impact category, the 2 sites with no boat waves and no trampling experienced net deposition. The 10 other survey sites with impact categories that included boat waves and/or trampling experienced net erosion. The survey results suggesed that foot-traffic trampling and boat waves are contributing influences to shoreline erosion in the study area.

Summer and fall surveys were not adequate to definitively differentiate and quantify erosion caused by a spring high water event. In order to better capture the contribution flood events may have on shoreline erosion or deposition, surveys would need to be completed at the end of March just after ice out, before Memorial Day in May after Labor Day in September and immediately following all flood events.

Please refer to Chapter 9 for additional discussion on the contributing influence flood flows may have on shoreline erosion and deposition.


Northern end of study area (approx)
LOWER ST. CROIX
NATIONAL SCENIC RIVERWAY
Shoreline Erosion Study
High Bridge area
LOWER ST. CROIX NATIONAL SCENIC RIVERWAY
N
W
E
S
Minnesota
Wisconsin
Arrow points to study area
Boomsite area
Federal Zone
State Zone
0.3
0
0.3
0.6 Miles
Southern end of study area (approx)
Map produced by the National Park Service, 12/98

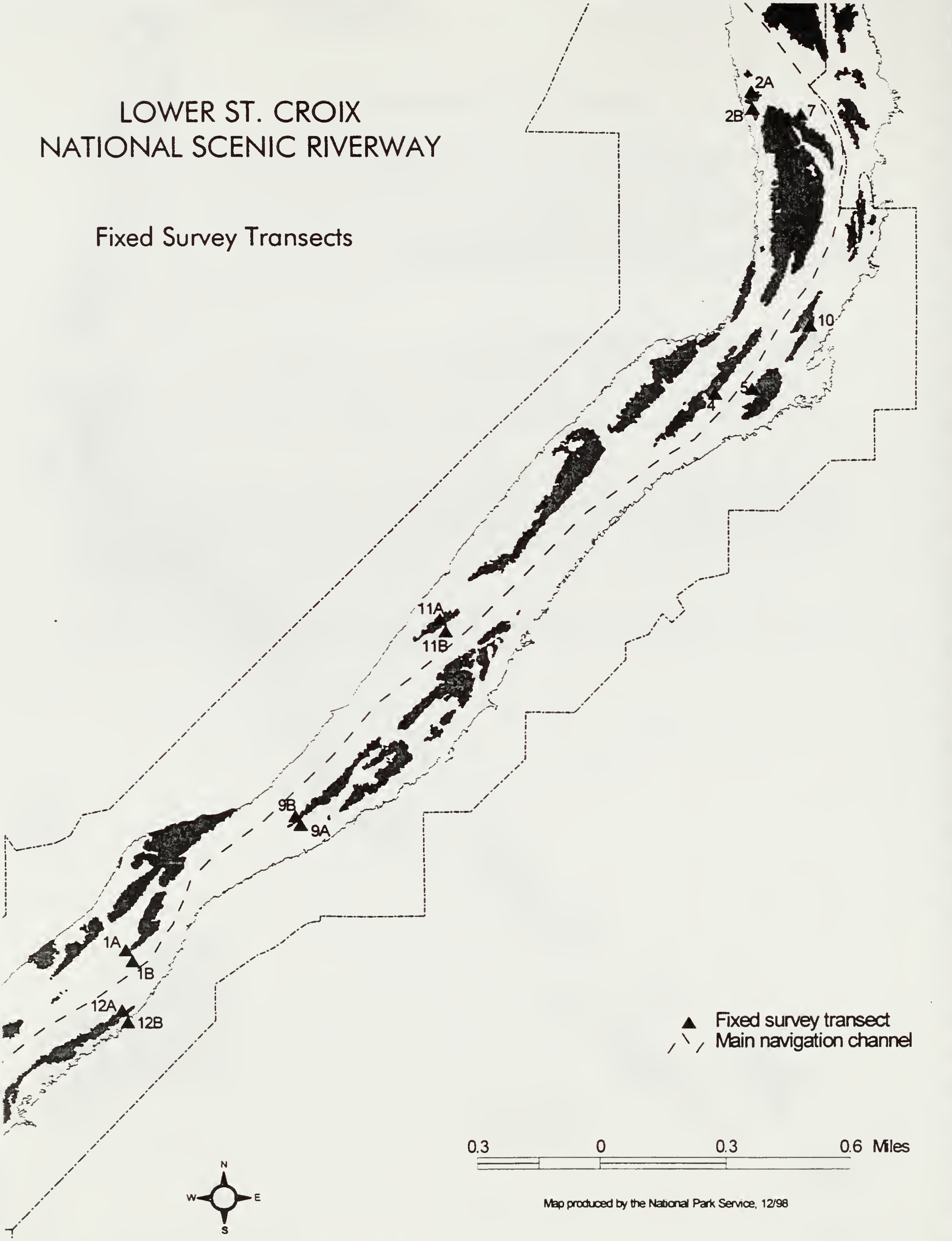


Figure 2. Fixed Survey Transects Location Map.

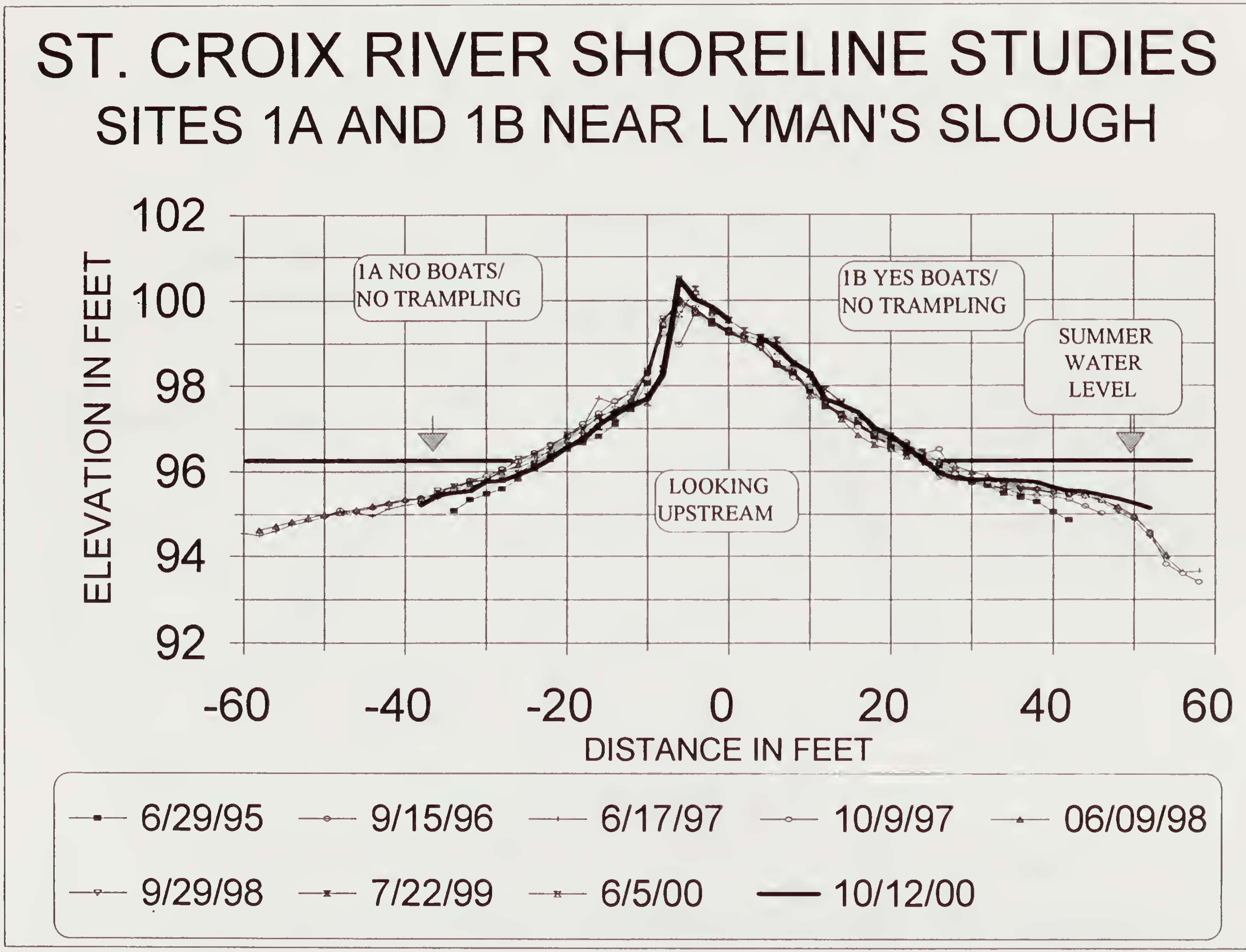


FIGURE 3. Shoreline Profile at Sites 1A and 1B near Lyman's Slough.

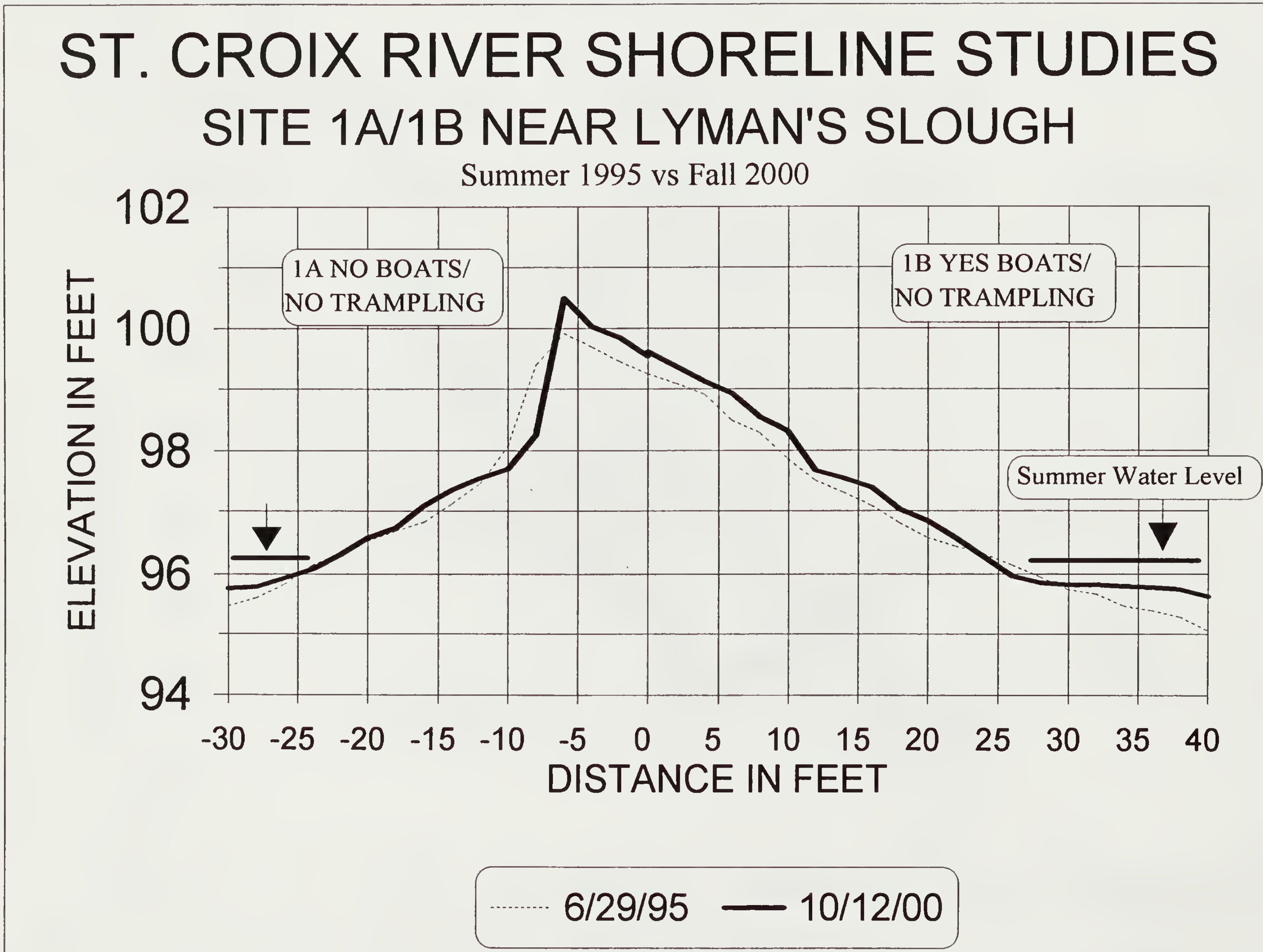


FIGURE 4. A Comparison of 1995 and 2000 Shoreline Profile at Sites 1A and 1B near Lyman's Slough.

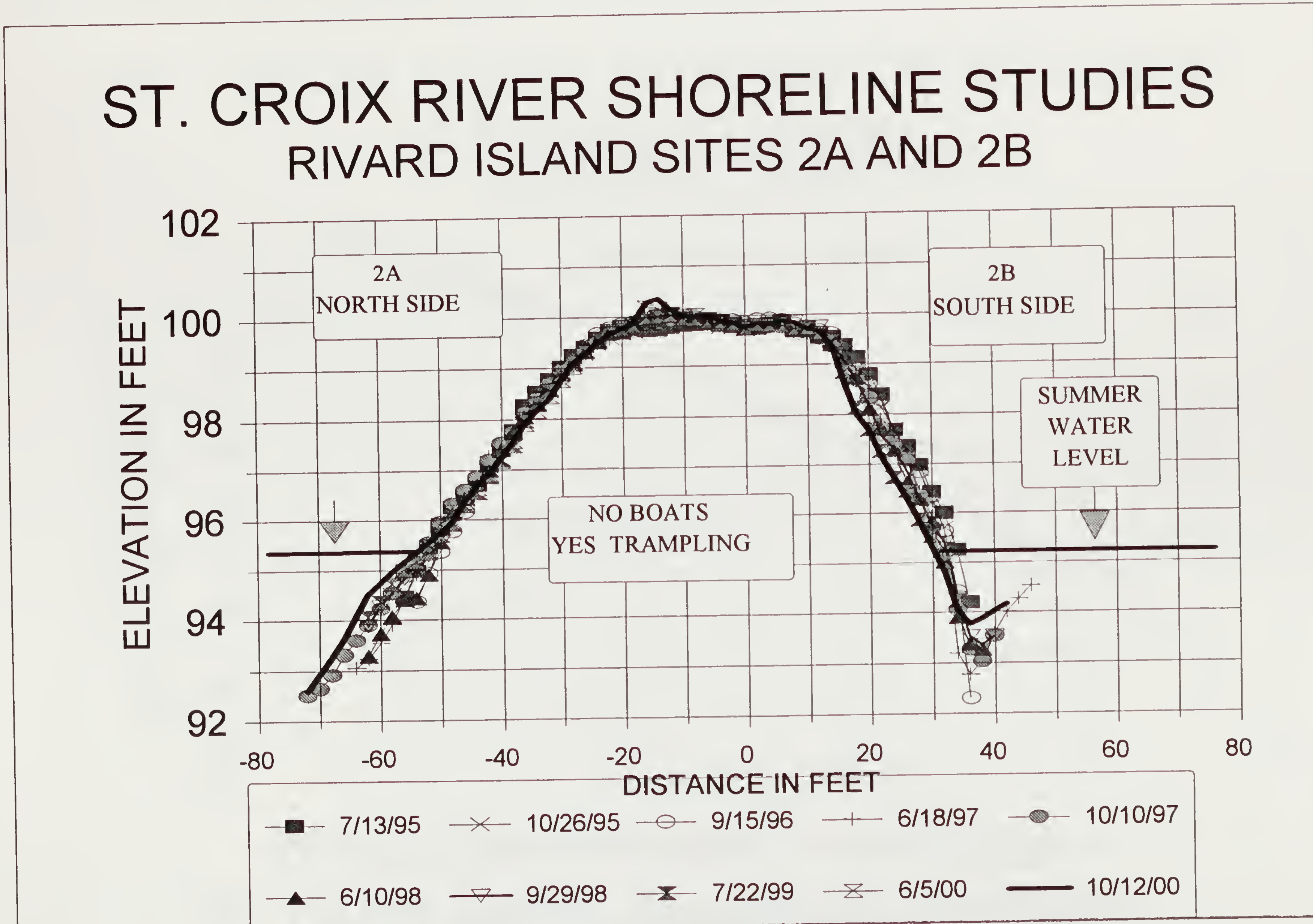


Figure 5. Shoreline Profiles at Sites 2A and 2B on Rivard Island.

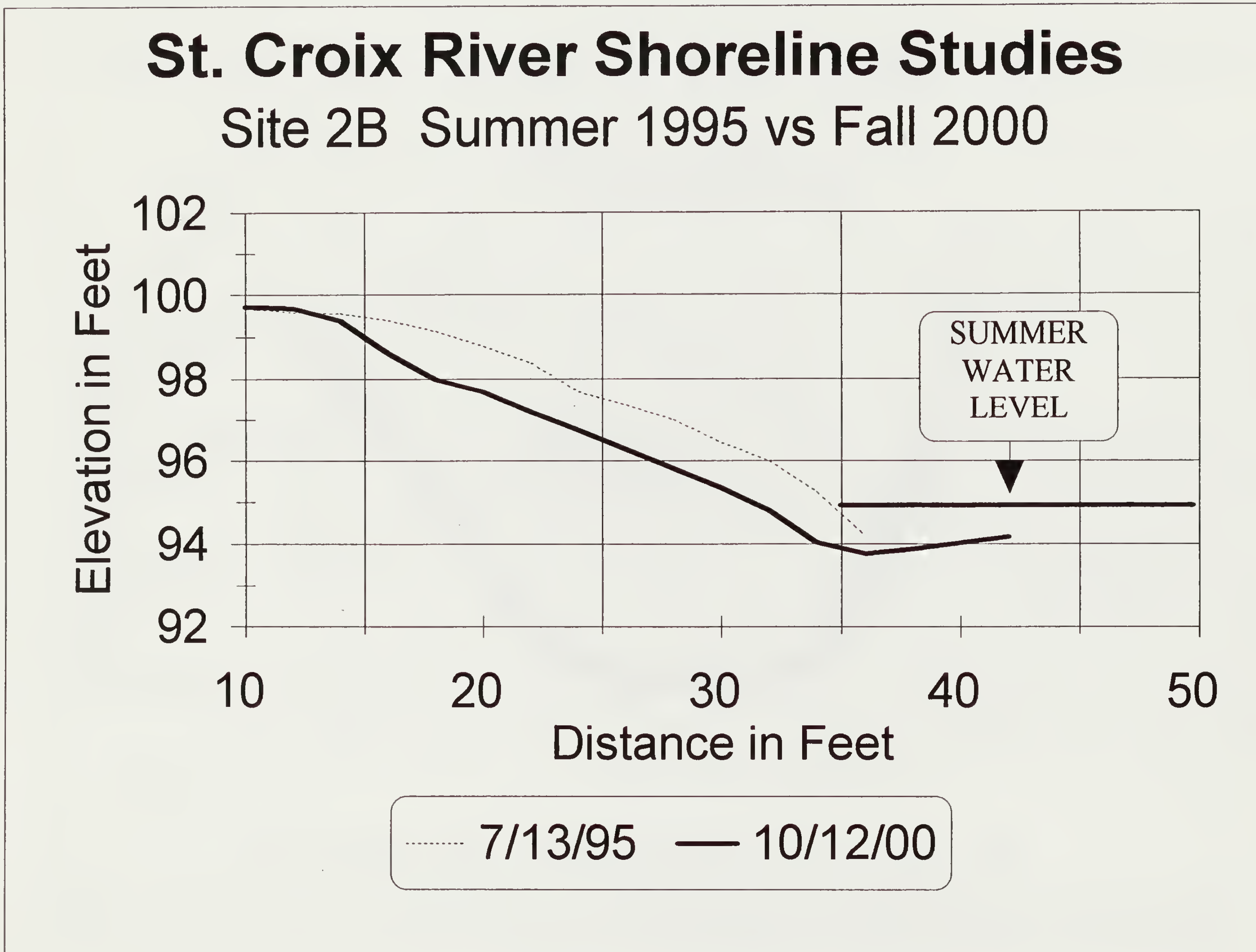


Figure 6. A Comparison of 1995 and 2000 Shoreline Profiles at Site 2B on Rivard Island.

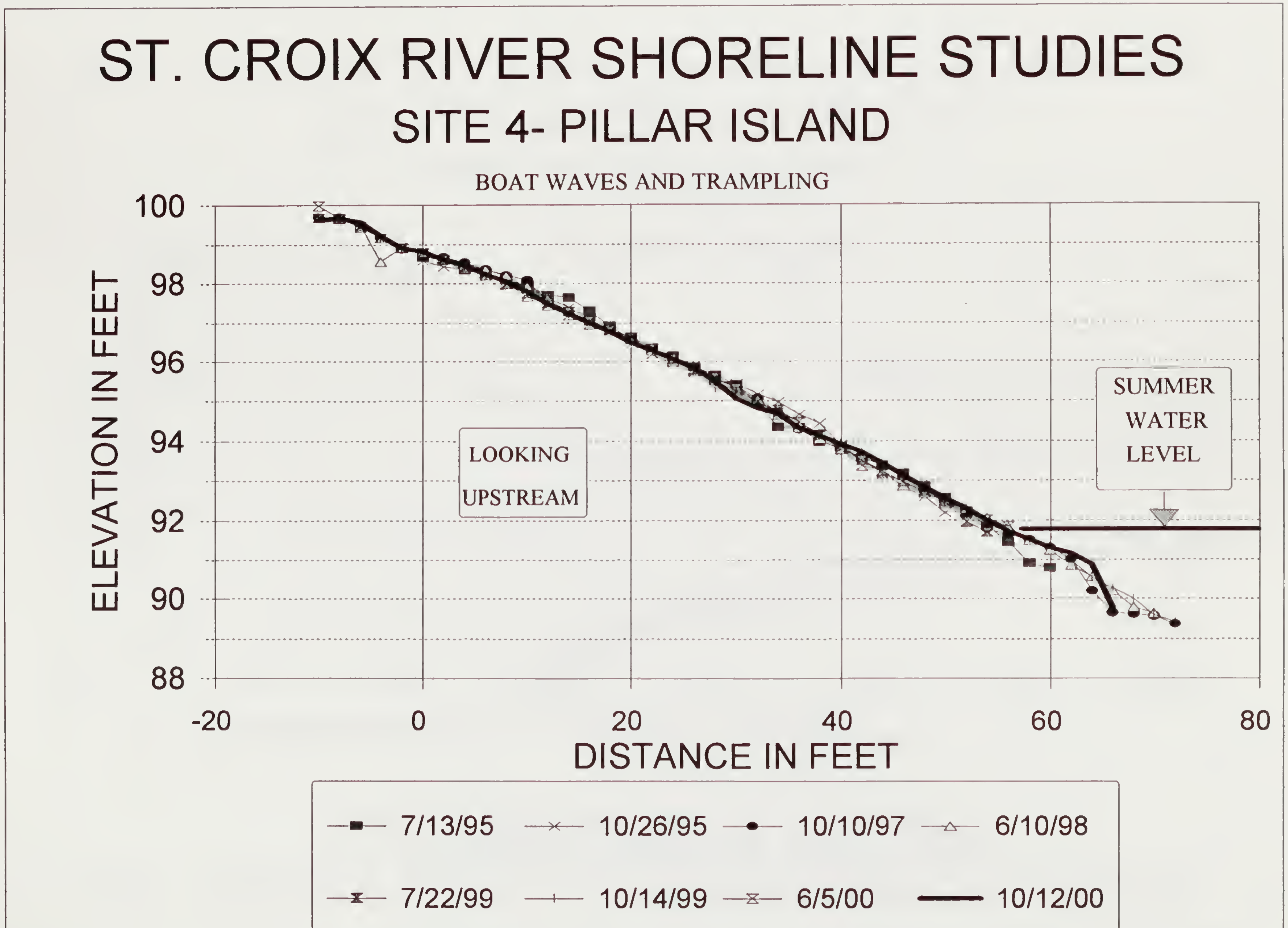


FIGURE 7. Shoreline Profile at Site 4 on Pillar Island.

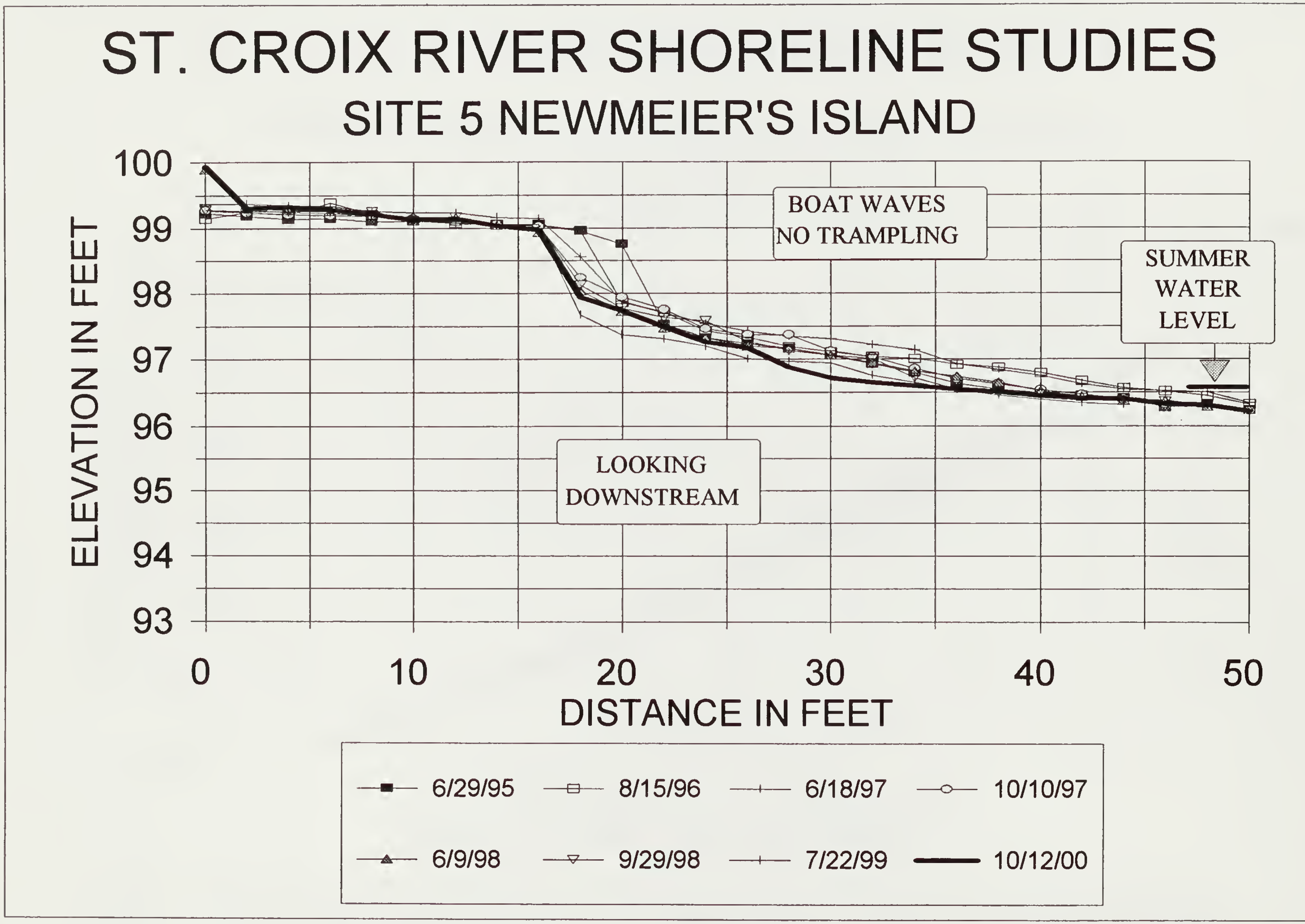


FIGURE 8. Shoreline Profiles at Site 5 on Newmeier's Island.

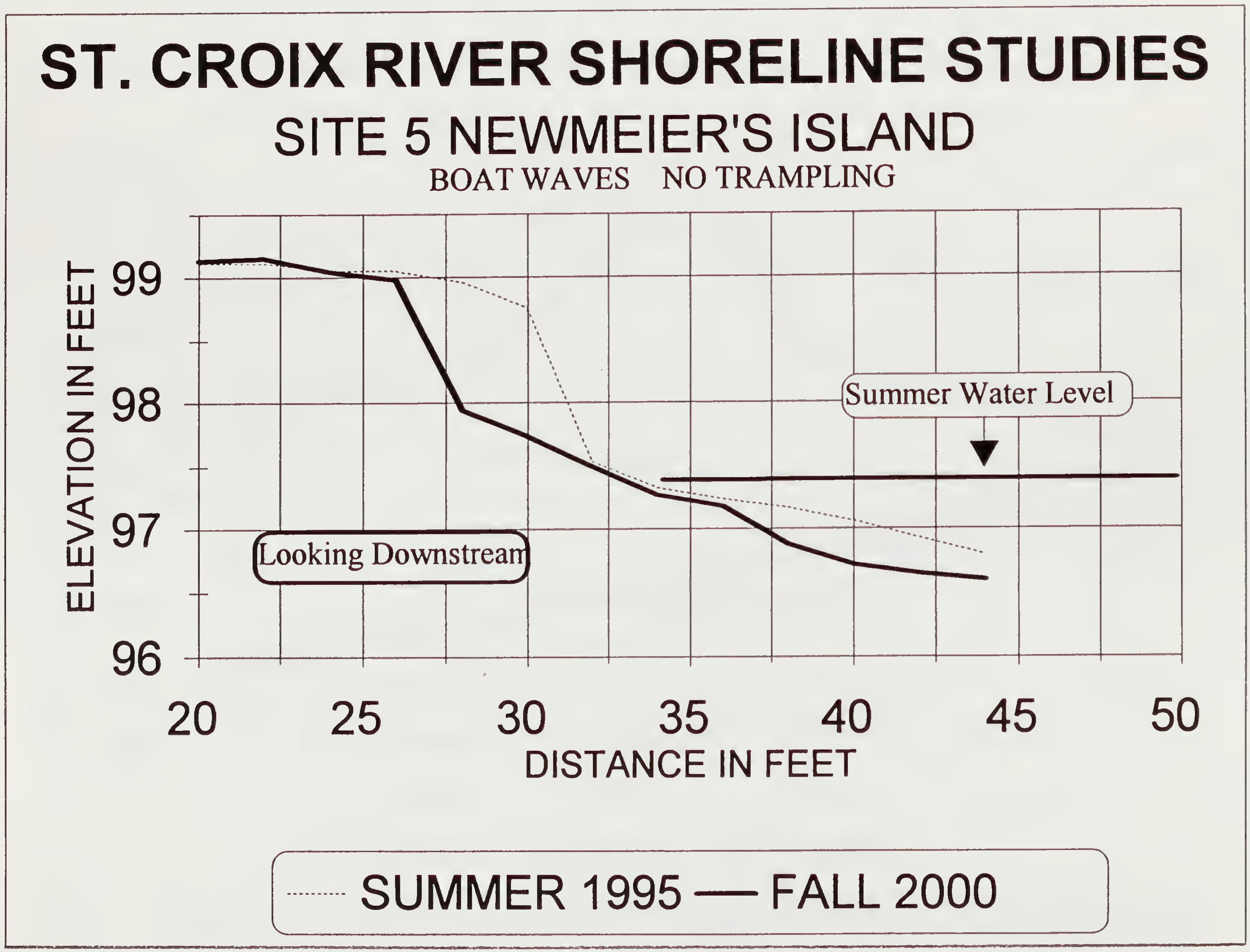


FIGURE 9. A Comparison of 1995 and 2000 Shoreline Profiles at Site 5 on Newmeier's Island.

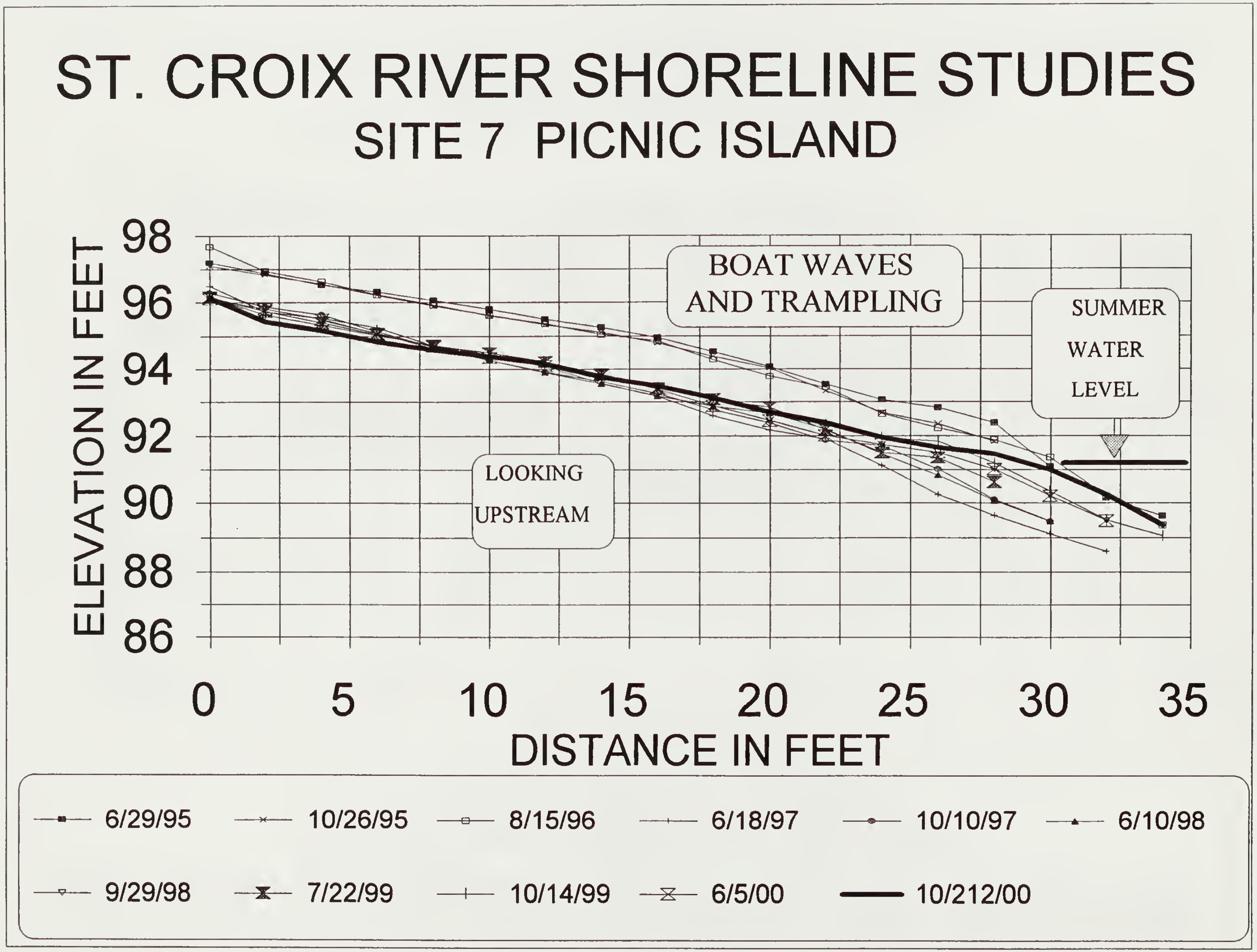


FIGURE 10. SHORELINE PROFILE AT SITE 7 PICNIC ISLAND.

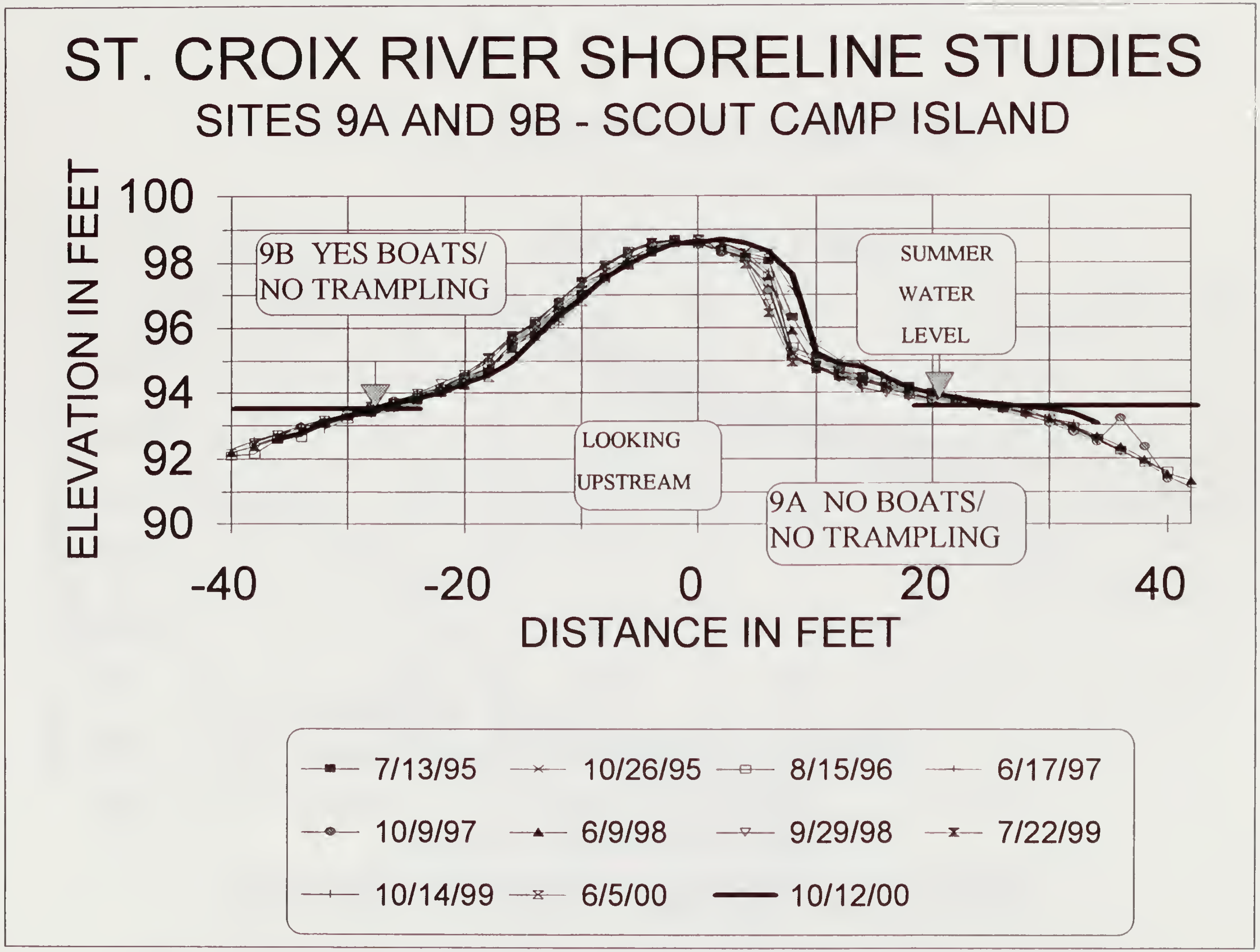


FIGURE 11. Shoreline Profiles at Sites 9A and 9B on Scout Camp Island.

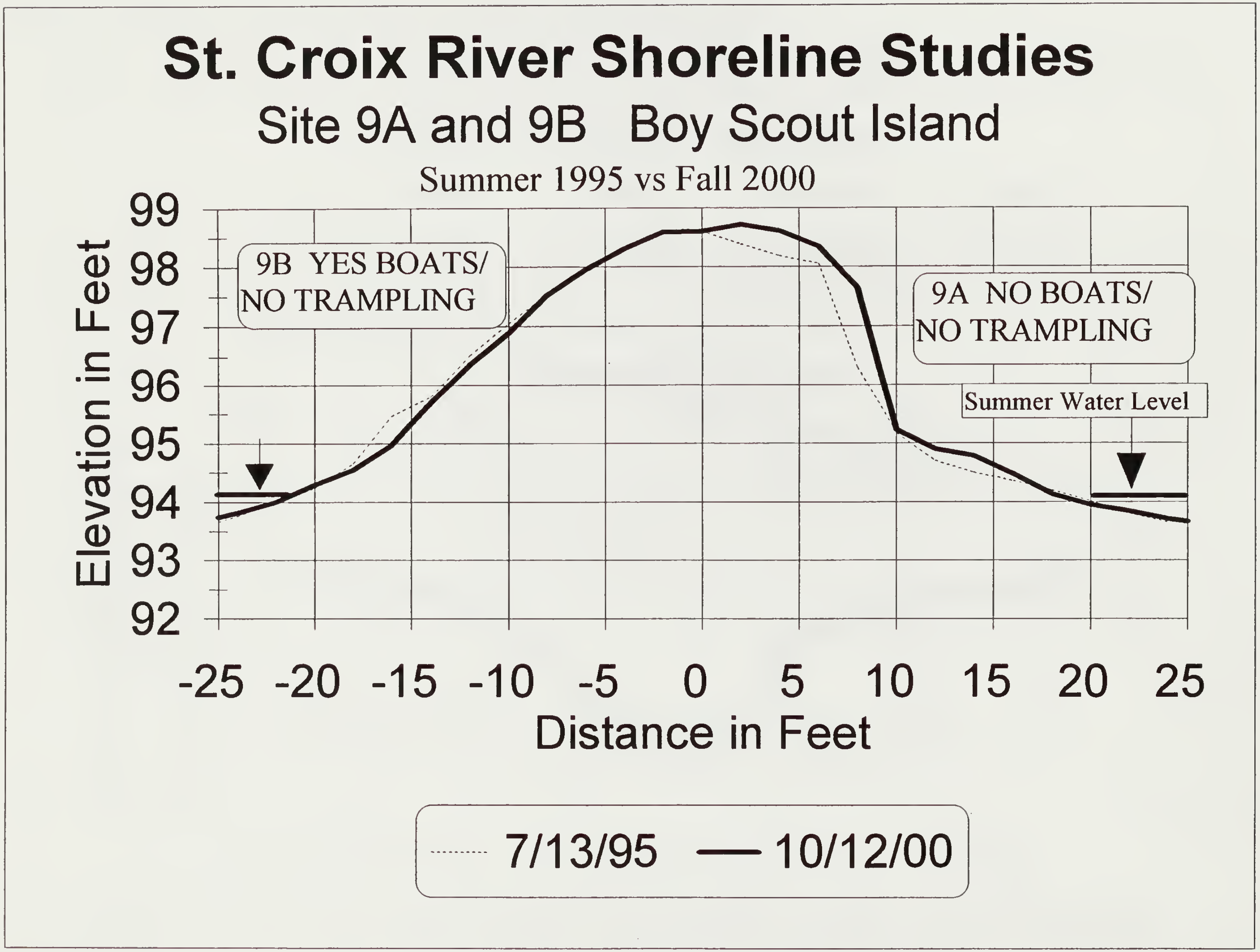


FIGURE 12. A Comparison of 1995 and 2000 Shoreline Profiles at Sites 9A and 9B on Scout Camp Island.

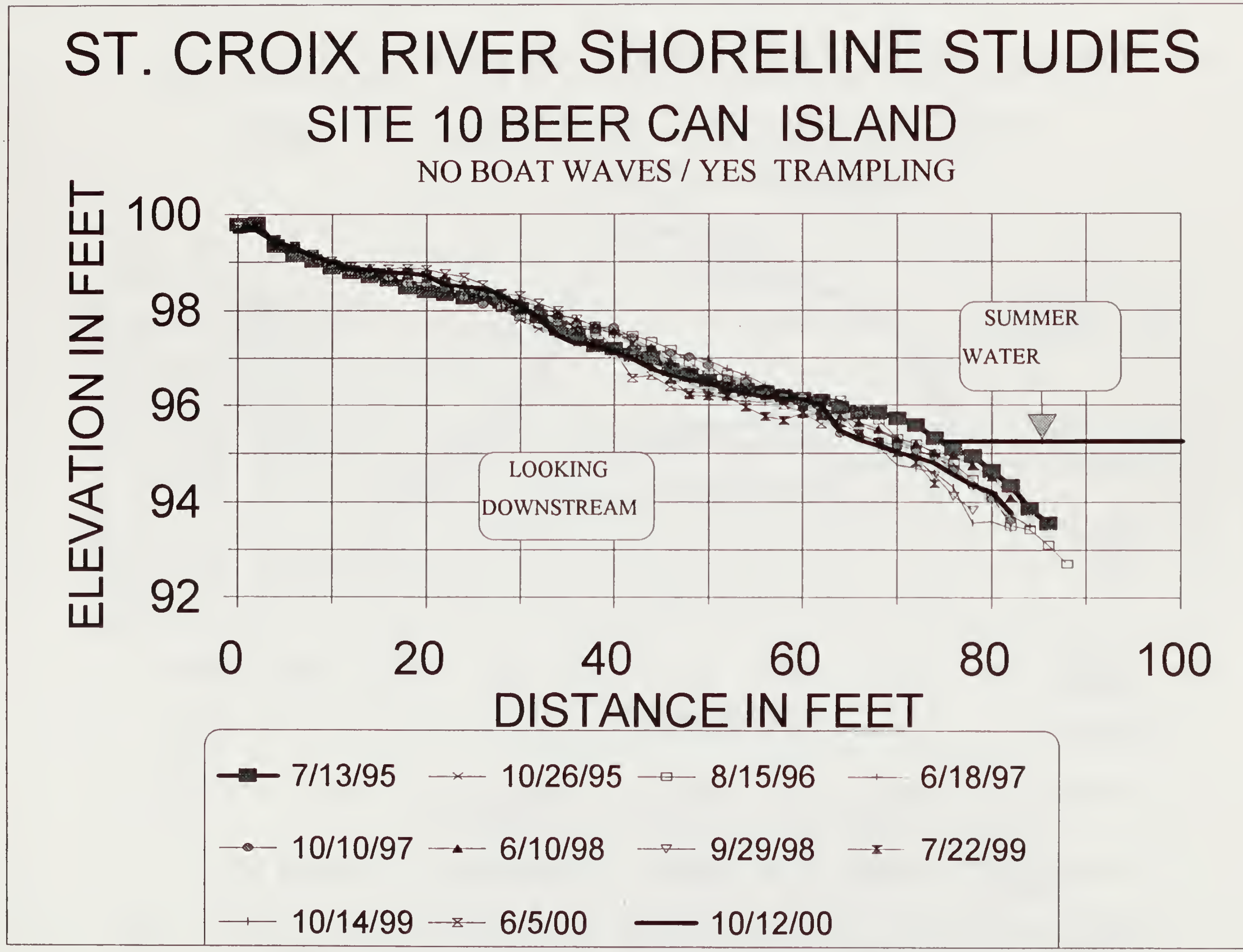


FIGURE 13. Shoreline Profiles at Site 10 on Beer Can Island.

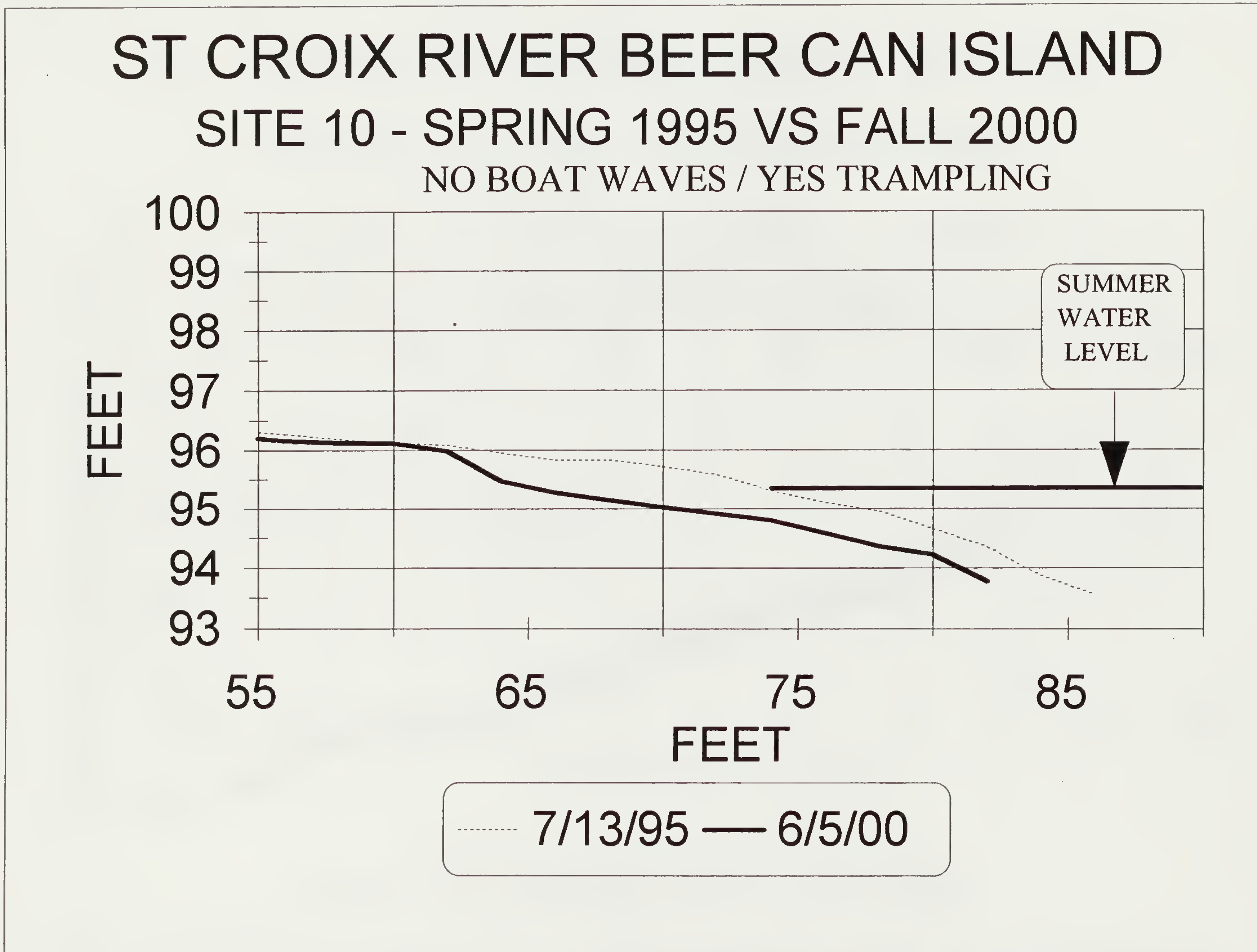


FIGURE 14. A Comparison of 1995 and 2000 Shoreline Profiles at Site 10 on Beer Can Island.

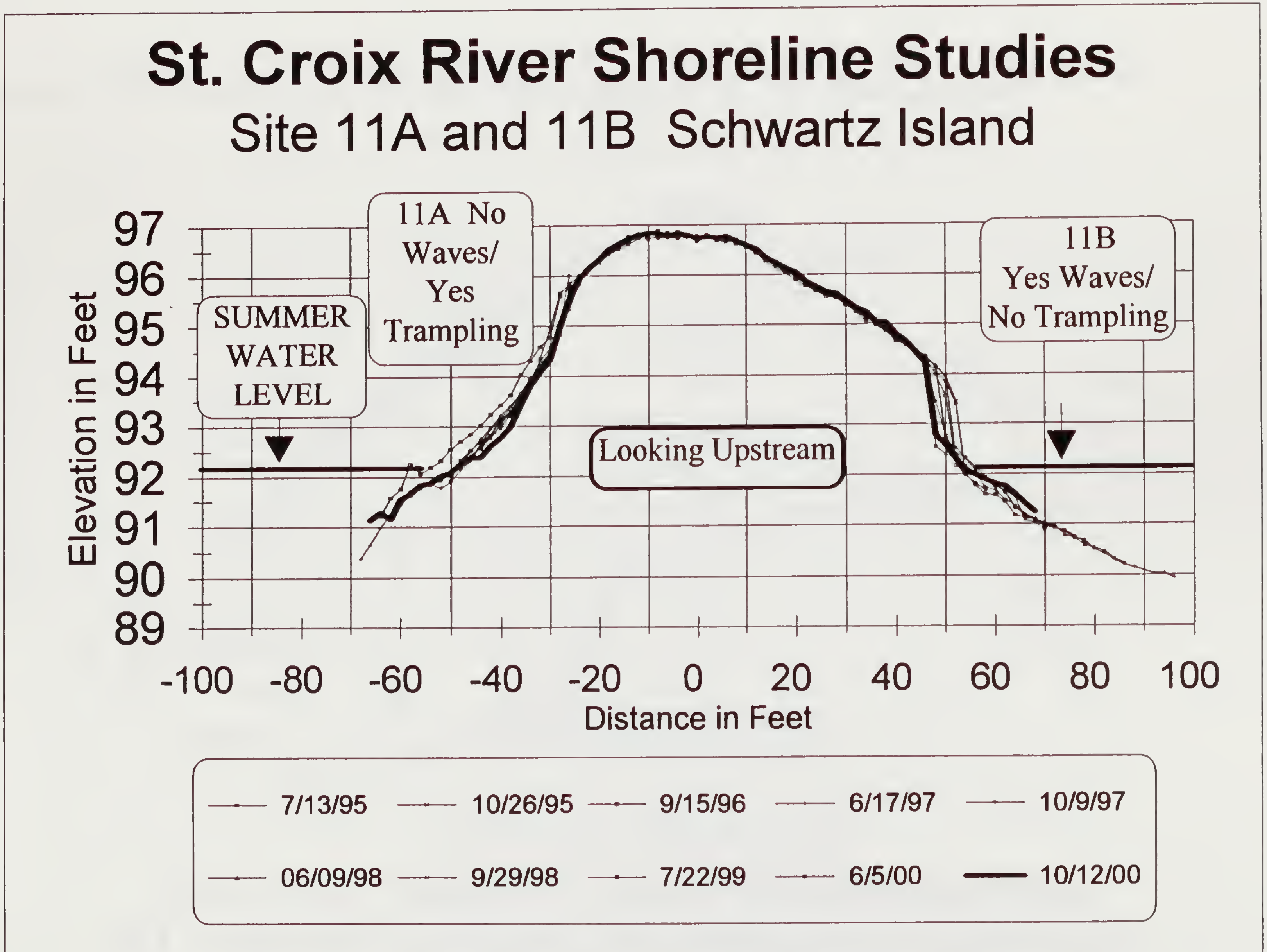


FIGURE 15. Shoreline Profiles at Sites 11A and 11B on Schwartz Island.

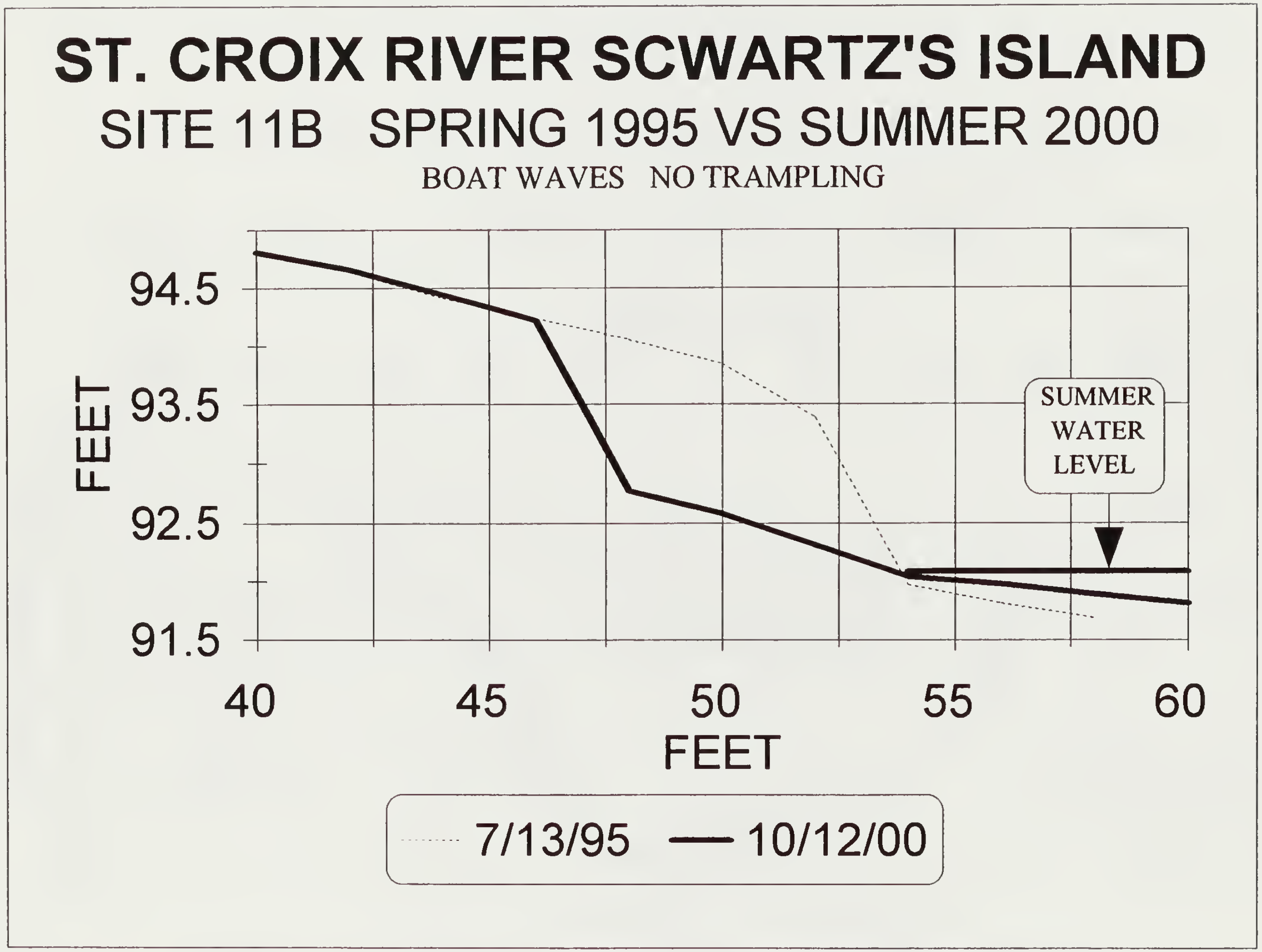


FIGURE 16. A Comparison of 1995 and 2000 Shoreline Profiles at Site 11B on Schwartz Island.

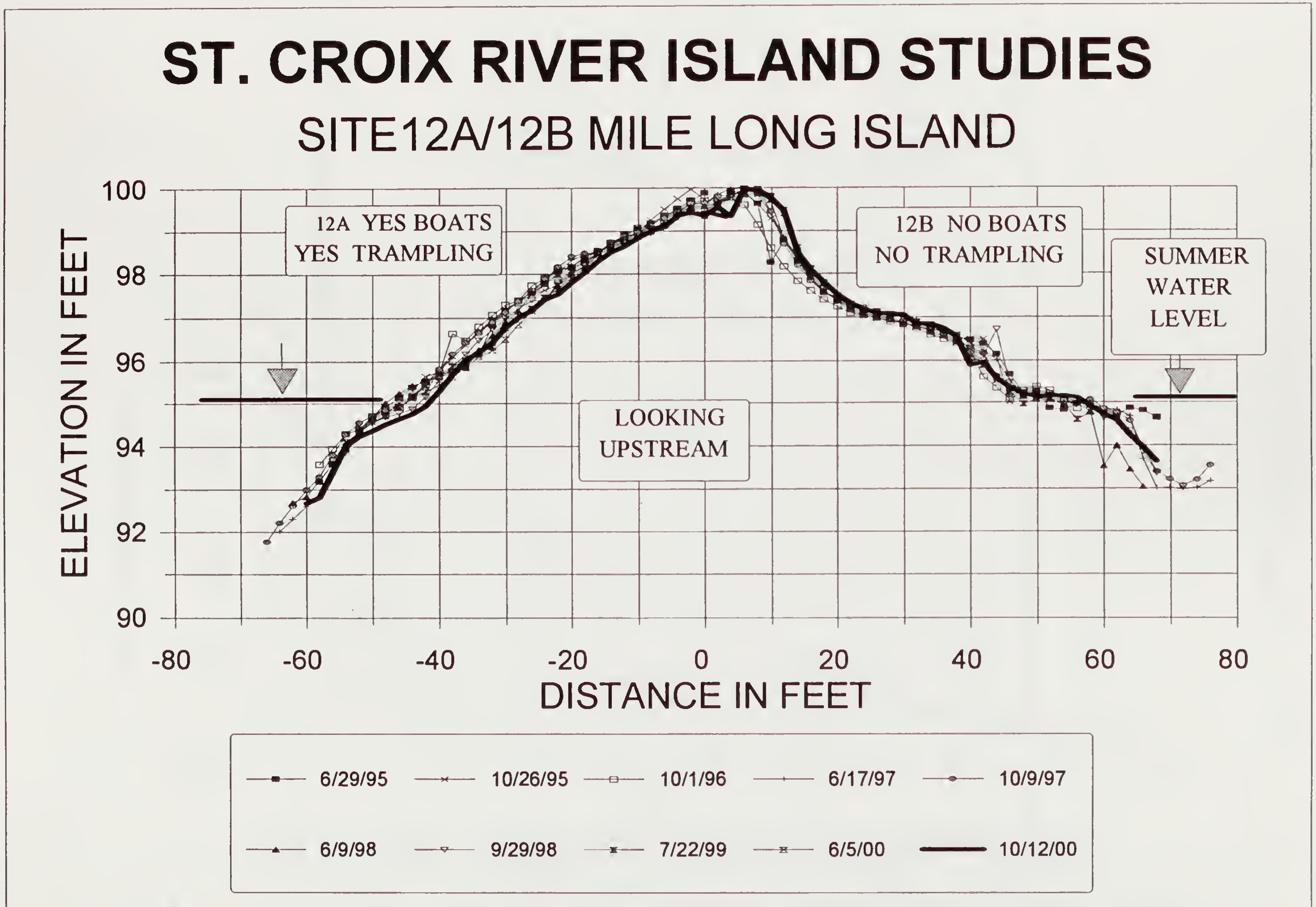


Figure 17. Shoreline Profiles at Sites 12A and 12B on Mile Long Island.

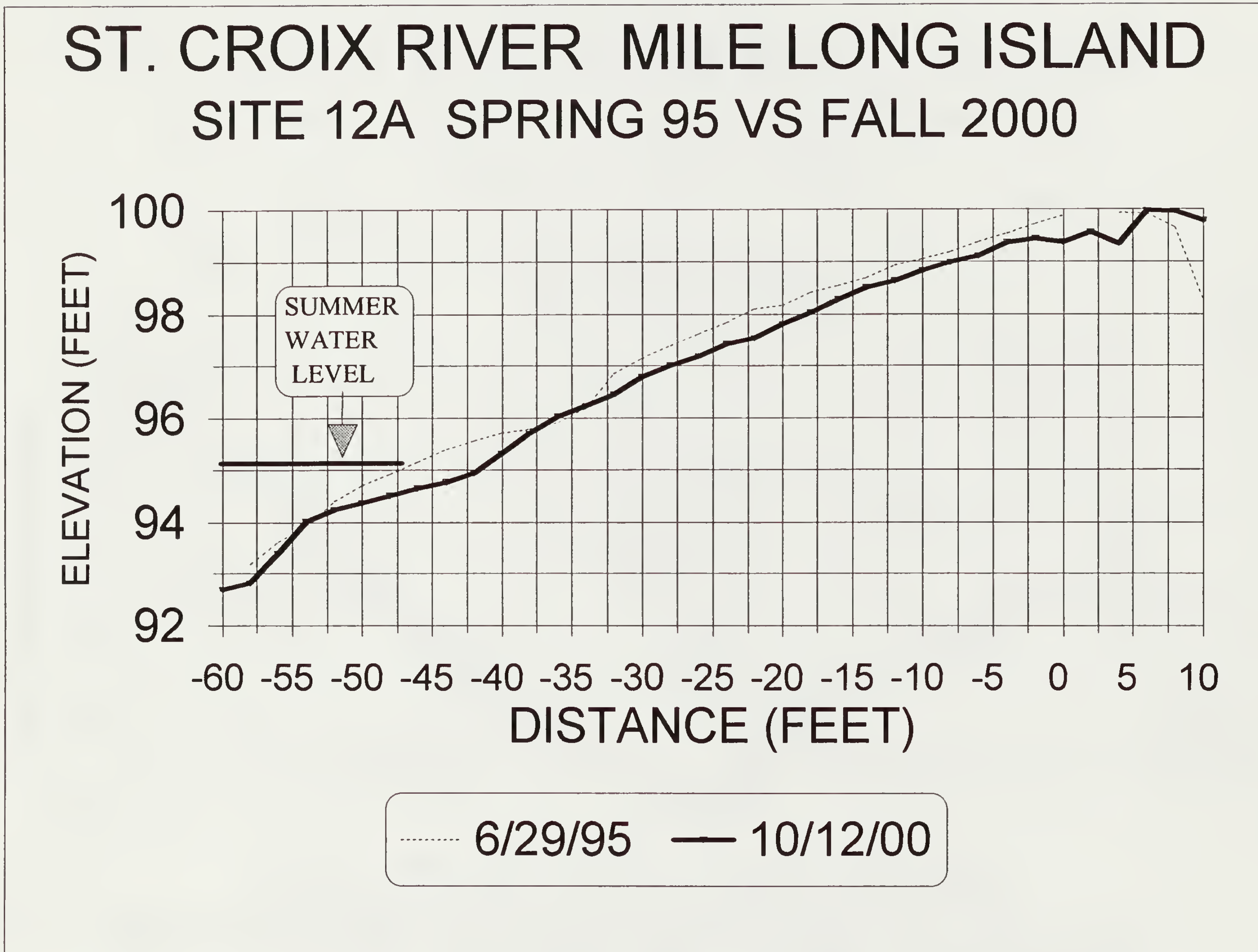


Figure 18. A Comparison of 1995 and 2000 Shoreline Profiles at Site 12A on Mile Long Island.

Recreational Boating Survey Transect Matrix
To Assist in Site Selection

←----------TRANSECTS----------→

CRITERIA ↓ ↓ ↓	1	2	3	4	5	6	7	8	9	10	11	12	TOTAL SITES
NO BOATS NO TRAMP	A								A			B	3
NO BOATS YES TRAMP		A B								X	A		4
YES BOATS NO TRAMP	B				X				B		B		4
YES BOATS YES TRAMP				X			X					A	3

"X" : Denotes only one site at island

Table 1. Recreational Boating Survey Transect Matrix

St. Croix River Shoreline Survey Summary

	Island Site	Treatment	Summer 95	Fall 95	Fall 96	Summer 97	Fall 97	Summer 98	Fall 98	Summer 99	Fall 99	Summer 00	Fall 00	Net Deposition or Erosion (feet)
1	1A	NBNT	Start	NS	+	+-	0	0	0	-	NS	+	-	-1.5
2	1B	YBNT	Start	NS	+-	+	+	- +	-+	+	NS	-	+-	2.5
3	2A	NBYT	Start	0	-	+	+	-	+	0	NS	-	-	-1
4	2B	NBYT	Start	0	0	0	0	0	0	0	NS	-	0	-3
5	4	YBYT	Start	+ -	NS	NS	+ -	- +	NS	0	0	0	0	-1
6	5	YBNT	Start	NS	- +	+-	-	-	+-	-	NS	NS	+	-3
7	7	YBYT	Start	-	0	-	+	+	+	-	+	0	+	-1
8	9A	NBNT	Start	-	0	0	-	+	-	-+	-	+	+	1
9	9B	YBNT	Start	+	-	0	0	0	0	-	-	-	+-	-1
10	10	NBYT	Start	-	+	0	-	+ -	-	-	+-	+	+	-9
11	11A	NBYT	Start	-	+	-	0	-	-	0	NS	0	-	-7
12	11B	YBNT	Start	0	+	-	-	0	-	+	NS	-	+	-6
13	12A	YBYT	Start	- +	- +	0	+	+-	+-	-	NS	-	-	-5
14	12B	NBNT	Start	0	-	+	-	-	+	0	NS	0	0	5

Sorted by Treatment - Overall Trend Summer 1995 to Fall 2000

					Eros/Treat
1	9A	NBNT	deposition	1	0/2
2	12B	NBNT	deposition	5	
3	5	YBNT	erosion	-3	
4	9B	YBNT	erosion	-1	3/3
5	11B	YBYT	erosion	-6	
6	2A	NBYT	erosion	-1	
7	2B	NBYT	erosion	-3	
8	10	NBYT	erosion	-9	4/4
9	11A	NBYT	erosion	-7	
10	4	YBYT	erosion	-1	
11	7	YBYT	erosion	-1	3/3
12	12A	YBYT	erosion	-5	

total sites
10/12

KEY
+ = deposition
- = erosion
+ - = mixed
0 = no net change
NS = no survey

NBNT = No Boat Waves or Trampling
YBNT = Yes Boat Waves/No Trampling
NBYT = No Boat Waves/YesTrampling
YBYT = Yes Boat Waves and Trampling

Table 2. St. Croix River Shoreline Survey Results.

Appendix 1. Spreadsheet Printout of Survey Data.

SITE 1A AND 1B

	STATION	6/29/95	9/15/96	6/17/97	10/9/97	06/09/98	9/29/98	7/22/99	6/5/00	10/12/00
	-60			94.54						
	-58			94.50		94.62				
	-56			94.60		94.72				
	-54			94.75		94.83				
	-52			94.84		94.92				
	-50			94.94	94.95	95.00				
	-48			95.04	95.10	95.05				
	-46			95.05	95.08	95.11				
	-44			94.96	95.16	95.20				
	-42			95.15	95.26	95.28				
	-40			95.22	95.32	95.36				
	-38			95.27	95.39	95.39	95.23			95.22
	-36			95.37	95.52	95.51	95.56			95.44
	-34	95.09		95.51	95.56	95.67	95.67			95.52
	-32	95.34		95.67	95.80	95.75	95.78			95.55
	-30	95.48		95.79	95.90	95.82	95.84			95.77
	-28	95.61		96.03	96.07	95.99	96.04	95.81		95.79
	-26	95.84		96.11	96.25	96.17	96.30	95.98	95.87	95.93
	-24	96.14		96.26	96.45	96.39	96.43	96.21	96.10	96.08
	-22	96.34		96.54	96.64	96.45	96.59	96.42	96.29	96.31
	-20	96.53		96.79	96.84	96.74	96.87	96.62	96.53	96.58
	-18	96.68		97.06	97.11	96.97	97.04	96.84	96.77	96.74
	-16	96.83	97.18	97.72	97.37	97.31	97.27	97.05	97.03	97.09
	-14	97.12	97.39	97.60	97.65	97.42	97.46	97.26	97.28	97.35
	-12	97.46	97.56	97.86	97.84	97.69	97.61	97.49	97.46	97.55
1A	-10	98.08	98.33	98.34	98.18	98.34	98.36	97.76	97.61	97.70
	-8	99.41	99.24	99.52	99.54	99.49	99.59	98.42	98.39	98.25
	-6	99.92	98.98	99.96	100.03	100.05	99.95	99.69	100.50	100.49
	-4	99.70	99.74	99.78	99.74	99.80	99.82	100.27	100.08	100.03
	-2	99.46	99.50	99.51	99.51	99.54	99.53	99.72	99.77	99.85
	0	99.25	99.26	99.29	99.32	99.32	99.31	99.57	99.54	99.55
	2	99.10	99.11	99.09	99.10	99.19	99.13	99.31	log	log
	4	98.92	98.92	98.87	98.89	99.09	98.90	99.16	99.13	99.13
	6	98.48	98.50	98.50	98.47	98.52	98.54	99.1	98.81	98.93
	8	98.28	98.31	98.24	98.19	98.41	98.31	98.54	98.53	98.54
1B	10	97.87	97.99	97.89	97.97	97.77	97.91	98.25	98.26	98.31
	12	97.51	97.56	97.62	97.60	97.62	97.60	97.91	97.92	97.68
	14	97.30	97.30	97.26	97.33	97.21	97.36	97.58	97.63	97.55
	16	97.09	97.05	97.10	97.04	96.85	97.15	97.31	97.19	97.39
	18	96.82	96.83	96.86	96.90	96.62	96.87	96.92	96.77	97.03
	20	96.58	96.65	96.75	96.81	96.52	96.73	96.85	96.67	96.85
	22	96.45	96.54	96.52	96.69	96.35	96.62	96.61	96.45	96.58
	24	96.32	96.26	96.16	96.43	96.32	96.25	96.47	96.29	96.28
	26	96.14	95.87	96.04	96.52	96.26	95.93	96.22	96.14	95.97
	28	95.95	95.80	95.96	95.92	96.13	95.85	96.04		95.86
	30	95.75	95.75	95.85	95.83	95.99	95.77			95.82
	32	95.67	95.66	95.77	95.77	95.90	95.71			95.82
	34	95.48	95.59	95.70	95.75	95.80	95.61			95.80
	36	95.40	95.49	95.60	95.64	95.67	95.57			95.78
	38	95.29	95.44	95.56	95.58	95.62	95.56			95.75
	40	95.05	95.42	95.52	95.52	95.58	95.48			95.63
	42	94.85	95.34	95.46	95.45	95.49	95.45			95.55
	44		95.18	95.41	95.43	95.44				95.53
	46		95.01	95.30	95.35	95.33				95.44
	48			95.05	95.12	95.18				95.36
	50			94.85	94.92	94.96				95.25
	52			94.44	94.57	94.56				95.13
	54			93.96	93.81	94.03				
	56			93.64	93.60					
	58			93.66	93.41					
	60									

SITES 2A AND 2B - RIVARD ISLAND

	STATION	7/13/95	10/26/95	9/15/96	6/18/97	10/10/97	06/10/98	9/29/98	7/22/99	6/5/00	10/12/00
	-74.00										92.37
	-72					92.52					92.60
	-70					92.66					92.93
	-68					92.93					93.27
	-66					93.32					93.63
	-64				93.07	93.61					94.06
	-62				93.24	93.91	93.30	93.90	94.07		94.50
	-60				93.55	94.23	93.74	94.28	94.37		94.73
	-58				93.92	94.54	94.08	94.53	94.72		94.96
	-56	94.46			94.45	94.87	94.40	94.83	95.00		95.18
	-54	94.99		94.37	94.91	95.26	94.43	94.97	95.18		95.36
	-52	95.47		94.94	95.37	95.56	94.91	95.31	95.36	95.50	95.56
	-50	95.85		95.38	95.77	95.96	95.57	95.58	95.70	95.92	95.75
	-48	96.26		95.79	96.16	96.33	96.13	95.94	95.92	96.18	95.95
	-46	96.49	96.40	96.17	96.51	96.61	96.44	96.35	96.28	96.36	96.38
	-44	96.74	96.71	96.77	96.88	96.89	96.71	96.67	96.54	96.62	96.68
	-42	97.09	97.17	97.16	97.29	97.21	97.00	96.90	96.86	96.90	96.95
	-40	97.41	97.46	97.51	97.51	97.54	97.40	97.30	97.22	97.19	97.24
	-38	97.79	97.78	97.68	97.75	97.77	97.77	97.58	97.49	97.57	97.57
	-36	98.27	98.05	98.06	98.05	98.12	98.05	98.01	97.97	97.90	97.90
	-34	98.53	98.29	98.43	98.33	98.40	98.29	98.39	98.32	98.16	98.19
	-32	98.78	98.60	98.70	98.63	98.70	98.57	98.67	98.56	98.44	98.39
	-30	99.02	98.90	98.80	98.91	98.96	98.89	98.81	98.88	98.75	98.76
	-28	99.25	99.10	99.19	99.13	99.11	99.09	99.03	99.07	99.01	99.07
	-26	99.41	99.25	99.45	99.39	99.35	99.31	99.26	99.34	99.32	99.27
	-24	99.60	99.46	99.68	99.52	99.54	99.51	99.49	99.56	99.50	99.48
	-22	99.67	99.59	99.79	99.57	99.70	99.69	99.67	99.74	99.69	99.67
	-20	99.69	99.67	99.87	99.72	99.81	99.73	99.81	99.76	99.80	99.77
	-18	99.75	99.69	99.90	99.77	99.85	99.86	99.86	99.82	99.86	99.90
	-16	99.73	99.86	99.95	99.84	99.88	99.91	99.94	99.98	100.19	100.28
	-14	99.74	99.88	99.98	99.84	99.89	99.93	100.00	100.00	100.16	100.34
	-12	99.79	99.95	100.00	99.90	99.92	100.02	100.05	100.02	100.03	100.12
2A	-10	99.82	99.86	99.98	99.85	99.94	99.85	99.91	99.95	100.00	100.01
	-8	99.83	99.84	99.98	99.88	99.87	99.91	99.88	99.94	100.02	99.99
	-6	99.92	99.85	99.94	99.82	99.84	99.87	99.87	99.89	99.94	99.95
	-4	99.90	99.77	99.91	99.77	99.81	99.82	99.84	99.85	99.89	99.91
	-2	99.82	99.76	99.91	99.77	99.79	99.80	99.79	99.81	99.84	99.87
	0	99.79	99.71	99.85	99.75	99.79	99.74	99.80	99.76	99.74	99.77
	2	99.76	99.77	99.92	99.75	99.79	99.75	99.76	99.81		99.83
	4	99.83	99.77	99.93	99.79	99.80	99.79	99.77	99.80		99.83
	6	99.89	99.83	99.90	99.76	99.82	99.79	99.86	99.79		99.89
	8	99.74	99.76	99.82	99.65	99.75	99.69	99.86	99.73		99.86
2B	10	99.68	99.61	99.77	99.61	99.64	99.69	99.72	99.74		99.72
	12	99.58	99.54	99.69	99.50	99.52	99.56	99.76	99.63		99.67
	14	99.55	99.47	99.62	99.51	99.36	99.39	99.41	99.48		99.38
	16	99.39	99.22	99.33	99.27	98.97	99.15	99.09	98.84		98.63
	18	99.13	98.90	98.92	98.88	98.67	98.72	98.65	98.13		98.00
	20	98.79	98.53	98.61	98.29	98.33	98.10	98.19	97.70		97.69
	22	98.39	98.14	98.29	97.90	97.74	97.72	97.59	97.28		97.19
	24	97.69	97.70	97.69	97.59	97.40	97.28	97.33	96.74		96.74
	26	97.37	97.31	97.26	97.17	97.09	96.62	96.86	96.46		96.28
	28	96.99	96.89	96.84	96.46	96.36	96.28	96.27	95.89		95.82
	30	96.43	96.20	96.33	95.93	95.71	95.84	95.78	95.55		95.35
	32	96.00	95.71	95.65	95.41	95.20	95.03	95.41	95.02		94.81
	34	95.27		94.42	93.20	94.07	93.91	94.28	94.24		94.05
	36	94.20		92.31	92.79	93.28	93.39	93.53			93.78
	38				93.07	93.05	93.28	93.36			93.88
	40				93.59	93.54		93.54			94.03
	42				94.01						94.18
	44				94.27						
	46				94.53						

STIE 4 - PILLAR ISLAND

STATION	7/13/95	10/26	10/10/97	06/10/98	7/22/99	10/14/99	6/5/00	10/12/00
-10			99.70	99.69	99.69	99.69	99.99	99.62
-8			99.70	99.71	99.67	99.68	99.68	99.67
-6			99.52	99.51	99.48	99.53	99.45	99.57
-4			99.19	98.57	99.17	99.19	99.18	99.23
-2			98.90	98.92	98.93	98.92	98.92	98.92
0	98.68	98.59	98.80	98.83	98.79	98.78	98.80	98.82
2	98.60	98.44	98.68	98.67	98.61	98.59	98.62	98.61
4	98.35	98.38	98.54	98.47	98.39	98.47	98.44	98.47
6	98.23	98.21	98.37	98.36	98.21	98.22	98.20	98.23
8	98.10	98.06	98.22	98.21	97.98	98.03	97.99	98.07
10	97.96	97.94	98.09	97.91	97.75	97.81	97.68	97.81
12	97.71	97.64	97.55	97.60	97.51	97.54	97.46	97.49
14	97.66	97.41	97.26	97.32	97.30	97.21	97.20	97.23
16	97.31	97.12	97.11	97.06	97.06	96.99	96.97	97.00
18	96.93	96.78	96.82	96.82	96.82	96.84	96.79	96.78
20	96.58	96.46	96.65	96.57	96.62	96.61	96.65	96.48
22	96.32	96.18	96.35	96.29	96.36	96.27	96.34	96.29
24	96.16	95.95	96.09	96.01	96.07	96.03	96.08	96.06
26	95.86	95.70	95.84	95.76	95.75	95.77	95.79	95.85
28	95.66	95.52	95.56	95.56	95.60	95.32	95.51	95.48
30	95.41	95.44	95.37	95.31	95.31	95.19	95.24	95.06
32	94.93	95.17	95.07	95.03	94.93	94.91	94.98	94.82
34	94.36	94.98	94.71	94.65	94.79	94.72	94.72	94.67
36	94.35	94.67	94.30	94.34	94.49	94.40	94.49	94.33
38	93.99	94.45	94.02	94.06	94.18	94.19	94.16	94.15
40	93.84	93.93	93.79	93.78	93.86	93.96	93.80	93.93
42	93.59	93.51	93.58	93.52	93.52	93.72	93.38	93.72
44	93.40	93.24	93.36	93.21	93.16	93.43	93.23	93.45
46	93.19	92.84	93.08	92.86	92.98	93.04	92.96	93.13
48	92.86	92.59	92.76	92.68	92.73	92.78	92.68	92.84
50	92.57	92.20	92.46	92.49	92.48	92.51	92.44	92.55
52	92.24		92.11	92.30	91.97	92.16	92.22	92.31
54	91.87		91.80	92.08	91.71	91.87	92.03	92.01
56	91.46		91.64	91.84		91.72	91.86	91.72
58	90.92		91.52	91.50		91.53		91.53
60	90.79		91.32	91.24		91.35		91.32
62			91.02	90.85		90.98		91.16
64			90.21	90.57		90.54		90.88
66			89.66	90.21		90.27		89.78
68			89.62	89.79		90.01		
70			89.57	89.64		89.60		
72			89.38			89.43		
74								
76								

SITE 5 - NEWMEIRERS ISLAND

STATION	6/29/95	8/15/96	6/17/97	10/10/97	06/09/98	9/29/98	7/22/99	10/12/00
0	99.23	99.16	99.38	99.28	99.90	99.29	99.90	99.94
2	99.19	99.25	99.38	99.25	99.31	99.27	99.29	99.31
4	99.14	99.21	99.35	99.22	99.28	99.27	99.25	99.33
6	99.16	99.39	99.34	99.20	99.27	99.27	99.23	99.29
8	99.11	99.22	99.26	99.19	99.22	99.26	99.19	99.22
10	99.11	99.12	99.24	99.16	99.18	99.13	99.13	99.13
12	99.11	99.08	99.24	99.10	99.17	99.18	99.09	99.15
14	99.05	99.06	99.17	99.07	99.05	99.07	99.06	99.04
16	99.05	99.06	99.15	99.04	98.94	99.07	99.02	98.98
18	98.96	98.97	98.57	98.25	98.04	98.13	97.68	97.94
20	98.76	97.87	97.89	97.95	97.73	97.78	97.38	97.74
22	97.54	97.72	97.71	97.76	97.48	97.64	97.32	97.50
24	97.33	97.44	97.55	97.47	97.33	97.59	97.21	97.27
26	97.24	97.34	97.43	97.38	97.21	97.28	97.01	97.18
28	97.17	97.20	97.36	97.38	97.17	97.14	96.97	96.88
30	97.06	97.12	97.32	97.13	97.07	97.07	96.95	96.72
32	96.93	97.05	97.23	97.04	96.95	97.01	96.76	96.65
34	96.80	97.01	97.15	96.86	96.82	96.72	96.65	96.60
36	96.64	96.92	96.94	96.71	96.74	96.55	96.54	96.55
38	96.55	96.88	96.85	96.63	96.65	96.50	96.46	96.51
40	96.49	96.80	96.76	96.54	96.53	96.48	96.40	96.45
42	96.46	96.68	96.63	96.47	96.44	96.42	96.35	96.42
44	96.42	96.57	96.55	96.41	96.38	96.39	96.32	96.41
46	96.28	96.52	96.53	96.33	96.38	96.37		96.33
48	96.33	96.45	96.50	96.29	96.29	96.31		96.31
50	96.24	96.33	96.35	96.23	96.24	96.24		96.22
52	96.21	96.17	96.33	96.21	96.17	96.15		96.10
54	96.16	96.22	96.25	96.19	96.15			96.10
56	96.03	96.06	96.16	96.12	96.11			96.02
58	95.92	95.91	96.03	96.04	96.10			95.91
60		95.73	95.90	95.90				
62		95.40	95.79	95.74				
64		95.06	95.59	95.58				
66		94.61	95.27	95.33				
68		94.34	94.90	94.91				
70			94.54					
72			94.24					
74			93.87					
76			93.60					
78			93.28					
80			93.39					

SITE 7 - PICNIC SITE

STATION	6/29/95	10/26/95	8/15/96	6/18/97	10/10/97	6/10/98	9/29/98	7/22/99	10/14/99	6/5/00	10/12/00
0	97.20	97.10	97.68	96.50	96.29		96.10	96.16	96.16	96.16	96.13
2	96.87	96.83	96.95	95.73	95.87		95.81	95.74	95.64	95.57	95.44
4	96.53	96.55	96.62	95.55	95.64	95.47	95.50	95.40	95.34	95.33	95.18
6	96.31	96.22	96.23	95.26	95.15	95.10	95.09	95.05	95.03	95.08	94.85
8	96.06	95.89	95.92	94.73	94.69	94.64	94.70	94.73	94.75	94.79	94.60
10	95.80	95.63	95.61	94.38	94.28	94.28	94.35	94.51	94.45	94.47	94.40
12	95.51	95.35	95.38	94.11	93.93	93.91	94.12	94.23	94.08	94.03	94.17
14	95.27	95.12	95.06	93.56	93.62	93.54	93.82	93.86	93.86	93.69	93.74
16	94.96	94.81	94.86	93.16	93.24	93.17	93.37	93.40	93.44	93.40	93.48
18	94.54	94.40	94.30	92.59	92.76	92.86	92.87	93.07	93.05	92.98	93.11
20	94.08	94.03	93.78	92.19	92.38	92.66	92.45	92.83	92.67	92.66	92.69
22	93.53	93.32	93.44	91.93	91.88	92.22	92.02	92.19	92.31	92.41	92.38
24	93.05	92.68	92.65	91.13	91.73	91.47	91.76	91.52	91.96		91.97
26	92.82	92.35	92.25	90.25	91.02	90.83	91.52	91.37	91.86		91.67
28	92.39	91.85	91.89	89.64	90.11	90.07	91.02	90.62	91.20		91.47
30	91.10		91.38	89.13	89.48	89.48	90.21		90.34		91.00
32	90.14		90.20	88.61			89.49		89.51		90.24
34	89.63		89.36						89.05		89.36
36											88.69
38											88.12
40											87.45

SITES 9A AND 9B - SCOUT CAMP ISLAND

	STATION	7/13/95	10/26/95	8/15/96	6/17/97	10/9/97	6/9/98	9/29/98	7/22/99	10/14/99	6/5/00	10/12/00
	-52											
	-50				91.36							
	-48				91.50							
	-46				91.71							
	-44				91.88		91.84					
	-42			91.98	92.10		92.08					
	-40			92.10	92.30		92.31					
	-38			92.16	92.54	92.42	92.43	92.49				
	-36			92.59	92.75	92.66	92.78	92.74				92.59
	-34			92.66	93.01	92.97	92.94	92.93				92.77
	-32			93.09	93.20	93.11	93.20	93.18		92.89		93.07
	-30			93.21	93.36	93.40	93.39	93.36		93.21		93.31
	-28	93.39		93.42	93.56	93.59	93.66	93.61		93.34		93.38
	-26	93.56		93.73	93.76	93.77	93.78	93.67	93.68	93.45		93.66
	-24	93.76		93.88	93.99	93.95	94.00	94.00	93.85	93.74		93.82
	-22	94.00		94.14	94.16	94.18	94.27	94.32	94.06	93.94	94.04	94.00
	-20	94.23	94.36	94.49	94.55	94.53	94.50	94.60	94.46	94.22	94.23	94.29
	-18	94.66	94.72	94.79	94.97	94.99	95.06	95.10	95.12	94.51	94.49	94.55
	-16	95.46	95.55	95.53	95.67	95.70	95.72	95.73	95.78	95.01	95.13	94.96
	-14	95.80	96.10	95.95	96.14	96.14	96.17	96.20	96.12	95.63	95.74	95.69
	-12	96.52	96.62	96.52	96.79	96.80	97.23	96.78	96.78	96.12	96.21	96.36
9B	-10	97.05	97.16	97.05	97.40	97.44	97.46	97.45	97.41	96.76	96.79	96.89
	-8	97.54	97.72	97.57	97.91	97.87	97.92	97.94	97.91	97.42	97.51	97.52
	-6	97.91	98.13	98.11	98.33	98.33	98.36	98.36	98.29	97.89	97.95	97.95
	-4	98.31	98.35	98.46	98.53	98.58	98.59	98.63	98.61	98.39	98.38	98.31
	-2	98.62	98.64	98.63	98.68	98.68	98.68	98.71	98.68	98.60	98.60	98.59
	0	98.60	98.72	98.73	98.60	98.59	98.59	98.60	98.57	98.70	98.69	98.60
	2	98.39	98.64	98.38	98.38	98.31	98.38	98.39	98.38	98.59	98.60	98.72
	4	98.19	98.35	98.19	98.14	98.12	98.18	98.10	97.95	98.34	98.32	98.61
	6	98.06	98.33	97.61	97.26	97.13	96.97	96.71	96.45	97.72	98.13	98.35
	8	96.32	97.19	95.42	95.14	95.07	94.85	95.08	94.94	95.27	95.19	97.65
9A	10	95.16	95.48	95.10	94.85	94.77	94.60	94.81	94.84	94.99	94.80	95.23
	12	94.70	95.03	94.82	94.42	94.45	94.44	94.53	94.62	94.70	94.50	94.90
	14	94.50	94.90	94.52	94.12	94.33	94.37	94.16	94.34	94.39	94.33	94.79
	16	94.36	94.55	94.15	94.02	94.31	94.18	93.97	94.14	94.15	94.20	94.47
	18	94.20		93.92	94.01	93.94	94.09	93.85	93.91	94.06	94.12	94.14
	20	94.02		93.82	93.80	93.79	93.86	93.68	93.75	93.97		93.95
	22	93.80		93.74	93.67	93.68	93.71	93.62		93.85		93.84
	24	93.65		93.64	93.53	93.61	93.62	93.55		93.72		93.71
	26			93.50	93.42	93.48	93.46	93.48		93.64		93.62
	28			93.37	93.27	93.32	93.30	93.34		93.48		93.56
	30			93.17	93.10	93.06	93.10	93.21		93.18		93.49
	32			92.94	92.88	92.78	92.82	92.90		93.05		93.36
	34			92.59	92.52	92.50	92.51	92.58				93.06
	36			92.24	92.21	93.21	92.20	92.21				
	38			91.88	91.88	92.35	91.74					
	40			91.63	91.46	91.39	91.34					
	42				91.14							
	44											
	46											

SITE 10 - BEER CAN ISLAND

STATION	7/13/95	10/26/95	8/15/96	6/18/97	10/10/97	06/10/98	9/29/98	7/22/99	10/14/99	6/5/00	10/12/00
0	99.79	99.68	99.69	99.78	99.80	99.69	99.77	99.70	99.69	99.70	99.66
2	99.81	99.81	99.80	99.78	99.76	99.78	99.74	99.72	99.67	99.76	99.67
4	99.34	99.32	99.36	99.45	99.45	99.44	99.39	99.49	99.44	99.45	99.43
6	99.14	99.17	99.30	99.25	99.31	99.34	99.31	99.35	99.28	99.35	99.27
8	99.03	99.01	99.18	99.11	99.11	99.12	99.13	99.15	99.11	99.18	99.14
10	98.90	98.89	98.95	98.99	98.94	99.00	98.99	98.97	98.92	99.04	99.01
12	98.80	98.80	98.81	98.85	98.82	98.90	98.82	98.84	98.82	98.91	98.90
14	98.71	98.74	98.75	98.74	98.75	98.90	98.74	98.80	98.74	98.88	98.84
16	98.65	98.65	98.70	98.67	98.69	98.83	98.74	98.79	98.63	98.87	98.79
18	98.48	98.51	98.63	98.62	98.58	98.74	98.75	98.78	98.60	98.88	98.78
20	98.40	98.42	98.49	98.48	98.58	98.68	98.72	98.74	98.59	98.86	98.73
22	98.34	98.38	98.46	98.47	98.46	98.69	98.50	98.60	98.44	98.77	98.54
24	98.26	98.34	98.40	98.37	98.28	98.56	98.37	98.42	98.31	98.70	98.50
26	98.28	98.22	98.30	98.20	98.13	98.41	98.28	98.40	98.23	98.55	98.47
28	98.18	98.04	98.06	98.03	98.07	98.27	98.23	98.37	98.09	98.36	98.32
30	98.04	97.80	97.87	97.98	98.08	98.22	98.15	98.07	97.98	98.31	98.10
32	97.87	97.62	97.72	98.06	97.88	98.08	97.88	97.92	97.91	98.16	97.84
34	97.61	97.50	97.68	97.75	97.77	97.91	97.91	97.84	97.87	98.00	97.47
36	97.49	97.30	97.61	97.66	97.69	97.80	97.82	97.69	97.59	97.57	97.30
38	97.27	97.20	97.60	97.59	97.65	97.69	97.68	97.63	97.33	97.40	97.29
40	97.20	97.09	97.52	97.55	97.65	97.57	97.50	97.22	97.14	97.17	97.12
42	97.07	96.97	97.48	97.39	97.43	97.28	97.36	97.17	96.99	96.58	96.99
44	97.00	96.88	97.35	97.12	97.20	97.24	97.05	96.88	96.86	96.63	96.78
46	96.76	96.77	97.19	97.12	97.11	96.93	96.88	96.57	96.53	96.39	96.63
48	96.64	96.65	96.91	97.03	97.03	96.74	96.72	96.21	96.48	96.27	96.53
50	96.52	96.47	96.65	96.96	96.86	96.52	96.58	96.19	96.25	96.27	96.45
52	96.39	96.43	96.65	96.78	96.56	96.44	96.47	96.18	96.11	96.21	96.34
54	96.34	96.34	96.50	96.64	96.48	96.30	96.39	95.96	96.08	96.16	96.24
56	96.28	96.29	96.32	96.43	96.27	96.19	96.31	95.76	96.05	96.21	96.17
58	96.19	96.17	96.28	96.29	96.18	96.09	96.24	95.68	96.12	96.00	96.13
60	96.13	96.21	96.19	95.98	96.19	96.02	96.14	95.82	95.93	95.84	96.12
62	96.09	96.14	96.16	95.90	95.78	95.91	95.97	95.79	95.79	95.60	95.98
64	95.95	96.09	96.11	95.85	95.41	95.74	95.80	95.62	95.51		95.47
66	95.83	95.92	95.81	95.57	95.37	95.63	95.41	95.41	95.35		95.28
68	95.83		95.69	95.45	95.25	95.50	95.24	95.24	95.13		95.15
70	95.72		95.31	95.28	95.17	95.30	95.09	95.03	94.77		95.03
72	95.58		95.20	95.09	95.07	95.20	94.89	94.83	94.70		94.92
74	95.31		95.01	94.93	94.96	95.03	94.57	94.39	94.62		94.81
76	95.10		94.81	94.75	94.67	94.97	94.14		94.31		94.58
78	94.96		94.48	94.33	94.34	94.76	93.84		93.57		94.36
80	94.66		94.15	94.13	94.07	94.53			93.60		94.22
82	94.35		93.51	93.75	93.62	94.11			93.45		93.78
84	93.87		93.43	93.49		93.86					
86	93.56		93.11			93.55					
88			92.72								

SITE 11A AND 11B SCHWARTZ ISLAND

	STATION	7/13/95	10/26/95	9/15/96	6/17/97	10/9/97	06/09/98	9/29/98	7/22/99	6/5/00	10/12/00
	-82										
	-80										
	-78										
	-76										
	-74										
	-72										
	-70										
	-68				90.38						
	-66				90.65						91.14
	-64			91.21	90.99						91.29
	-62			91.58	91.26						91.16
	-60			91.76	91.51	91.57		91.44			91.55
	-58			92.26	91.63	91.72	91.63	91.65			91.66
	-56			92.07	91.84	91.76	91.78	91.78			91.84
	-54			92.19	91.84	91.87	91.85	91.86			91.88
	-52			92.32	91.96	91.91	91.95	91.78			92.02
	-50	91.92		92.55	92.07	92.10	92.03	91.90			92.09
	-48	92.34		92.70	92.28	92.20	92.28	92.14			92.26
	-46	92.53		92.84	92.51	92.35	92.43	92.31			92.38
	-44	92.70		93.02	92.76	92.67	92.60	92.64	92.56		92.39
	-42	92.82	92.76	93.23	92.96	92.94	92.82	92.82	92.78		92.61
	-40	93.15	93.05	93.42	93.22	93.16	93.00	93.11	92.96		92.77
	-38	93.30	93.28	93.63	93.41	93.38	93.20	93.28	93.27	93.25	92.99
	-36	93.64	93.57	94.04	93.68	93.66	93.52	93.50	93.47	93.46	93.43
	-34	93.82	93.94	94.31	93.96	93.93	93.95	93.89	93.88	93.77	93.81
	-32	94.36	94.16	94.60	94.22	94.30	94.19	94.12	94.21	94.12	94.09
	-30	94.97	94.45	94.78	94.53	94.59	94.48	94.45	94.47	94.39	94.34
	-28	95.66	94.96	95.59	95.09	95.09	94.83	94.85	95.08	94.93	95.01
	-26	95.85	95.74	95.79	95.73	96.00	95.34	95.50	95.69	95.55	95.53
	-24	96.00	95.89	95.91	95.92	96.00	95.84	95.85	95.94	95.94	95.93
	-22	96.11	96.11	96.16	96.11	96.13	96.12	96.11	96.15	96.16	96.15
	-20	96.31	96.25	96.30	96.28	96.30	96.27	96.27	96.33	96.33	96.31
	-18	96.42	96.42	96.49	96.43	96.49	96.46	96.45	96.51	96.49	96.51
	-16	96.52	96.52	96.59	96.56	96.57	96.62	96.58	96.61	96.63	96.63
	-14	96.62	96.62	96.68	96.66	96.78	96.68	96.69	96.71	96.72	96.73
	-12	96.73	96.75	96.77	96.80	96.83	96.79	96.77	96.81	96.80	96.81
11A	-10	96.76		96.73	96.80	96.82	96.80	96.83	96.84	96.84	96.83
	-8	96.74		96.78	96.80	96.80	96.87	96.88	96.84	96.85	96.83
	-6	96.75		96.76	96.74	96.80	96.80	96.82	96.85	96.81	96.79
	-4	96.73		96.77	96.77	96.76	96.78	96.86	96.82	96.84	96.83
	-2	96.75		96.79	96.77	96.79	96.80	96.81	96.81	96.81	96.80
	0	96.75	96.65	96.78	96.66	96.66	96.69	96.78	96.69	96.68	96.73
	2	96.74	96.75	96.78	96.78	96.76	96.79	96.78	96.78	96.79	96.77
	4	96.69	96.69	96.67	96.72	96.70	96.75	96.73	96.75	96.73	96.74
	6	96.66	96.64	96.78	96.72	96.71	96.72	96.71	96.72	96.72	96.77
	8	96.66	96.71	96.62	96.65	96.65	96.66	96.65	96.64	96.66	96.67
11B	10	96.61	96.54	96.55	96.59	96.59	96.60	96.58	96.60	96.60	96.60
	12	96.46	96.43	96.44	96.46	96.45	96.47	96.47	96.49	96.49	96.51
	14	96.31	96.26	96.28	96.33	96.30	96.31	96.31	96.33	96.33	96.34
	16	96.19	96.13	96.18	96.22	96.20	96.19	96.22	96.21	96.22	96.24
	18	96.11	96.01	96.03	96.09	96.07	96.11	96.08	96.15	96.11	96.12
	20	95.92	95.89	95.89	95.94	95.94	95.96	95.96	96.01	96.03	96.05
	22	95.81	95.76	95.76	95.81	95.80	95.80	95.81	95.82	95.86	95.87
	24	95.71	95.69	95.67	95.70	95.69	95.71	95.73	95.70	95.72	95.76
	26	95.62	95.58	95.55	95.64	95.61	95.63	95.63	95.63	95.63	95.66
	28	95.56	95.54	95.53	95.56	95.53	95.52	95.53	95.53	95.54	95.62
	30	95.44	95.38	95.38	95.41	95.38	95.43	95.43	95.42	95.37	95.48
	32	95.30	95.30	95.25	95.29	95.30	95.30	95.29	95.25	95.30	95.34
	34	95.17	95.16	95.06	95.17	95.14	95.13	95.18	95.13	95.12	95.25
	36	95.05	94.98	94.99	95.04	95.00	95.06	95.00	95.00	95.02	95.05
	38	94.93	94.85	94.88	94.90	94.88	94.93	94.89	94.92	94.90	95.04
	40	94.81	94.65	94.68	94.77	94.73	94.74	94.75	94.76	94.72	94.81
	42	94.64	94.60	94.62	94.59	94.60	94.61	94.59	94.62	94.59	94.66
	44	94.41	94.42	94.43	94.43	94.43	94.48	94.43	94.47	94.46	94.44
	46	94.24	94.33	94.34	94.33	94.34	94.37	94.30	94.35	94.28	94.22
	48	94.05	94.14	93.98	94.18	94.15	94 16	93.44	94.14	92.54	92.77
	50	93.85	93.96	93.55	93.95	92.72	92.74	92.75	92.64	92.40	92.58
	52	93.39	93.45	92.17	92.30	92.32	92.41	92.39	92.52	92.28	92.31
	54	91.97		92.00	92.13	92.14	92.32	92.16	92.31		92.04
	56	91.81		91.77	91.98	92.01	92.13	92.03	92.06		91.98
	58	91.69		91.59	91.73	91.93	91.94	91.89	91.92		91.89
	60			91.58	91.67	91.81	91.77	91.79	91.71		91 81
	62			91.45	91.49	91.64	91.62	91.65			91.76
	64			91.18	91.37	91.34	91.33	91.54			91.60
	66			91.13	91.19	91.17	91.19	91.08			91.41
	68			91.10	91.10	91.07	91.07	91.03			91.24
	70			90.99	90.94	91.01	91.03	90.88			
	72			90.93	90.93	90.91	90.96				
	74				90.84	90.87	90.78				
	76				90.73	90.75	90.72				
	78				90.68	90.64	90.58				
	80				90.50	90.50	90.53				
	82				90.41		90 46				
	84				90.28		90.31				
	86				90.20		90.23				
	88				90.15						
	90				90.09						
	92				90.03						
	94				90.03						
	96				89.94						

	SITE 12A AND 12B MILE LONG ISLAND STATION	6/29/95	10/26/95	10/01/95	6/17/97	10/9/97	6/9/98	9/29/98	7/22/99	6/5/00	10/12/00
	-74										
	-72										
	-70										
	-68										
	-66					91.76					
	-64				92.01	92.21					
	-62				92.31	92.61	92.70				
	-60				92.61	92.99	92.84				92.68
	-58	93.18		93.60	92.83	93.30	93.22				92.81
	-56	93.62		93.95	93.35	93.82	93.61	93.68			93.39
	-54	93.93		94.30	93.85	94.29	94.00	94.10	94.12		94.02
	-52	94.40		94.42	94.32	94.56	94.29	94.34	94.33		94.24
	-50	94.71		94.65	94.67	94.71	94.68	94.56	94.59		94.37
	-48	94.92		94.80	94.87	94.84	95.02	94.68	94.72	94.74	94.51
	-46	95.15		94.91	94.98	94.93	95.24	94.78	94.91	95.02	94.64
	-44	95.39	95.31	95.18		95.14	95.43	94.87	95.13	95.17	94.76
	-42	95.55	95.65	95.47	95.26	95.49	95.53	95.16	95.43	95.27	94.94
	-40	95.70	95.77	95.75	95.80	95.82	95.64	95.56	95.68	95.45	95.30
	-38	95.78	96.13	96.66	96.10	96.18	95.74	95.89	95.91	95.63	95.69
	-36	95.91	96.39	96.50	96.41	96.45	95.88	96.18	96.03	95.86	96.03
	-34	96.18	96.68	96.81	96.71	96.67	96.28	96.50	96.18	96.12	96.23
	-32	96.84	96.95	97.08	96.97	96.91	96.61	96.74	96.34	96.27	96.45
	-30	97.15	97.17	97.30	97.22	97.13	96.91	97.00	96.77	96.52	96.78
	-28	97.39	97.39	97.41	97.38	97.39	97.16	97.23	97.07	96.85	97.01
	-26	97.62	97.53	97.75	97.54	97.63	97.59	97.41	97.22	97.17	97.18
	-24	97.84	97.64	97.92	97.77	97.90	97.79	97.41	97.47	97.46	97.43
	-22	98.11	97.77	98.10	98.05	98.18	98.00	97.83	97.67	97.74	97.54
	-20	98.18	98.05	98.17	98.34	98.41	98.20	98.08	97.92	98.00	97.81
	-18	98.42	98.19	98.27	98.45	98.50	98.35	98.33	98.16	98.20	98.03
	-16	98.55	98.47	98.51	98.55	LOG	98.56	98.47	98.45	98.53	98.29
	-14	98.69	98.69	98.74	98.67	98.75	98.64	98.59	98.70	98.70	98.51
	-12	98.93	98.87	98.79	98.86	98.90	98.77	98.78	98.81	98.89	98.64
12A	-10	99.05	98.98	98.97	98.95	98.96	98.87	98.85	98.90	99.09	98.83
	-8	99.19	99.27	98.99	99.13	99.16	99.01	98.95	99.05	99.13	98.99
	-6	99.37	99.52	99.19	99.33	99.31	99.18	99.06	99.20	99.14	99.11
	-4	99.53	99.76	99.41	99.49	99.41	99.41	99.31	99.43	99.44	99.35
	-2	99.72	99.97	99.70	99.63	99.66	99.57	99.39	99.48	99.54	99.44
	0	99.89	99.74	99.71	99.66	99.66	99.58	99.46	99.35	99.40	99.36
	2	TREE	TREE	99.71	99.85	99.81	99.67	99.68	99.62	99.58	99.56
	4	99.93	TREE	99.86	99.98	99.84	99.78	99.82	99.79	99.78	99.34
	6	99.91	99.89	99.61	99.99	99.96	99.85	99.92	99.99	99.97	99.97
	8	99.65	99.64	99.15	99.86	99.98	99.87	99.90	99.94	99.98	99.96
12B	10	98.26	99.30	98.61	99.42	99.46	99.72	99.80	99.81	99.80	99.78
	12	98.77	98.85	98.18	98.87	98.70	98.81	99.42	99.41	99.50	99.48
	14	98.31	98.37	97.84	98.38	98.20	98.30	98.50	98.61	98.55	98.50
	16	97.85	97.90	97.62	97.95	97.84	97.92	98.02	98.10	98.13	98.10
	18	97.57	97.61	97.41	97.71	97.60	97.62	97.77	97.80	97.80	97.81
	20	97.40	97.42	97.25	97.50	97.44	97.39	97.48	97.49	97.51	97.52
	22	97.23	97.28	97.11	97.31	97.25	97.19	97.28	97.30	97.30	97.32
	24	97.11	97.17	97.05	97.17	97.15	97.05	97.13	97.18	97.22	97.19
	26	96.98	97.03	96.98	97.11	97.08	96.99	97.09	97.11	97.13	97.10
	28	96.93	96.97	96.90	TREE	LOG	LOG	LOG	97.05	97.07	97.08
	30	96.87	96.88	96.87	97.02	96.93	96.84	96.96	97.02	LOG	97.07
	32	96.79	96.80	96.75	96.92	96.86	96.79	96.83	96.90	96.89	96.85
	34	96.72	96.73	96.60	96.77	96.75	96.67	96.77	96.80	96.84	96.85
	36	96.66	96.65	96.51	96.68	96.64	96.57	96.67	96.64	96.70	96.75
	38	96.51	96.55	96.40	96.57	96.46	96.44	96.55	96.54	96.59	96.56
	40	96.49	96.51	96.22	96.43	96.33	96.15	96.25	96.28	96.03	95.89
	42	96.39	96.51	95.61	96.25	96.16	95.89	96.14	95.90	95.99	95.96
	44	96.16	96.11	95.35	96.01	95.63	95.64	96.72	95.53	95.58	95.58
	46	95.68	95.00	95.05	95.53	95.18	95.32	95.47	95.24	95.34	95.36
	48	95.19		95.28	95.14	95.23	95.16	95.27	94.96	95.13	95.20
	50	95.24		95.38	95.15	95.18	95.12	95.26	95.07	95.20	95.13
	52	94.86		95.28	95.22	95.13	95.08	95.21	95.05	95.08	95.16
	54	94.82		95.06	95.06	95.03	94.98	95.13	94.94		95.15
	56	94.97		94.85	94.95	94.94	94.97	94.97	94.60		95.12
	58	94.90			94.95	95.06	94.78	94.96	94.76		94.92
	60	94.82			94.85	94.85	93.53	94.62			94.71
	62	94.68			94.82	94.76	94.00	94.63			94.59
	64	94.86			94.67	94.57	93.45	94.34			94.25
	66	94.80			93.69	93.95	93.05	93.86			93.97
	68	94.64			93.00	93.39		93.35			93.64
	70				93.02	93.22					
	72				92.98	93.07					
	74				93.02	93.21					
	76				93.17	93.54					

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 6

CHARACTERIZING SHORELINE SEDIMENT MOBILIZATION USING CONTROLLED RUNS

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ABSTRACT

In the Summer of 1996, 23 controlled recreational boat runs were completed at three sites on the St. Croix River. Wave characteristics, boat speed, sediment mobilization, and turbidity were measured for each run. The results suggest that a wave train generated by an individual recreational boat with a maximum wave height greater than 0.4 feet exceeds an erosive energy threshold. Exceedence of the threshold mobilizes nearshore and beach sands and temporarily increases turbidity.

INTRODUCTION AND PURPOSE OF STUDY

The Recreational Subcommittee of the St. Croix River Basin Water Resources Management Planning Team was tasked with the responsibility of investigating the effects of boat waves on shoreline sediment erosion, resuspension and deposition. The methods described in this Chapter allow researchers to quantify the relative amount of sediment mobilized by wave trains generated by recreational boats with varying maximum wave heights. For this study, sediment mobilization includes the erosion and resuspension of nearshore and beach sediments.

The Illinois State Water Survey (Bhowmik et al 1992) concluded that recreational boats on the Illinois and Mississippi Rivers are capable of generating waves of sufficient magnitude to necessitate an evaluation of their potential contribution to bank erosion or shoreline instability. In a study conducted by the Minnesota Department of Natural Resources (Johnson 1994), waves generated by recreational boats were identified as the predominant contributing influence responsible for the accelerated Mississippi River shoreline erosion near Red Wing. Researchers on the Gordon River (Nanson et al 1994) concluded that if recreational boat waves exceed an erosive energy threshold value, unconsolidated sandy shoreline sediments will erode and sediment will be resuspended into the water column. Nanson et al. (1994) found that of the numerous wave characteristics that can be measured or calculated, maximum wave height was the easiest to measure and correlated well with increased shoreline erosion.

METHODS

At three St. Croix River sites within the general study area, a recreational boat was used to generate incrementally higher maximum wave heights with successive controlled runs (figure 1). For this study, a controlled run is defined as a single pass of a recreational boat and the subsequent measurement of various wave and sediment mobilization characteristics. For all controlled runs, waves were generated by a 21 foot, V-hulled, 170 HP boat piloted by a Minnesota Department of Natural Resources Conservation Officer traveling upstream. A buoy anchored 90 feet from shore assured each controlled run maintained a 100 foot sailing line from the shoreline.

At each location, sediment traps, an ISCO water sampler and erosion pins were used to quantify the amount of sediment mobilized. At one site a Hydrolab water quality meter was used to measure turbidity. All sampling devices were located in approximately 1 foot of water depth. The controlled runs were completed on July 25 and August 19, 1996 when water levels were at 675.89 and 675.49, respectively. These water levels are representative of normal summer pool elevations. Sediments available for mobilization during the controlled runs were limited to the beach and nearshore zone. Banks with vertical scarp faces were not used in this investigation.

Two gages were installed at each site to measure maximum wave heights. Gage 1 was located nearshore (1 foot depth) to measure shallow water wave characteristics. Gage 2 was located in approximately 6 feet of water to measure deep water wave characteristics. A video camera was used to verify maximum wave heights at Gage 2 as read by research assistants in the field. A plan view of a typical site set up shows the relative position of the gages to the sampling and monitoring equipment (figure 2).

Two rectangular sediment traps 13.5 x 10.5 inches in size (1 square foot) and 1.5 inches deep were deployed at each site. To compare sampling efficiency, one sediment trap was oriented with its long axis parallel to shore while the other was oriented perpendicular to shore. A large meshed

screen, elevated from the trap bottom, was bolted into the trap to better retain sediment deposited during each run (figure 3). Both traps were staked to the river bottom to prevent them from being washed out of place by waves. The traps sampled only those sediment particles resuspended higher than 1.5 inches above the bottom of the river bottom and redeposited in the nearshore area.

The ISCO water sampler intake tube was attached to a threaded rod driven into the substrate and positioned 1 inch from the river bottom. Samples were taken in successive 1000 ml bottles as the wave train impinged on the shoreline for each controlled run. ISCO water samples were measured in Nephelometric Turbidity Units (NTUs) using a HACH Turbidimeter.

Erosion pins were placed perpendicular to the shoreline at 0.5 foot intervals both landward and waterward from the waterline. Each erosion pin was graduated in 0.1 inch increments and was pushed into the sand to the midpoint (zero) line (figure 4). Changes in the shoreline surface (erosion and deposition) were measured at each pin following a controlled run and then each pin was reset to the midpoint line for the next controlled run.

The Hydrolab was securely attached to a fence post driven into the bottom of the river channel with the probe positioned 1 inch from the bottom. The Hydrolab was programmed to measure turbidity in NTUs at 10 second intervals for each controlled run.

From each site, sediment samples were taken and analyzed for particle size in the laboratory. The following additional data were collected for each controlled run; boat velocity, number of waves in wave train, wave period, wave frequency, and wave celerity. A wave train is the entire set of waves generated by an individual pass of a recreational boat. Wave celerity is the speed at which a surface wave propagates through the water. See the Appendixes for more details regarding field set up, field data collection protocol, laboratory protocol and an example data collection sheet.

FINDINGS

Data were collected from a total of 23 controlled runs at 3 sites within the study area. The data from all runs were summarized and entered into a spreadsheet for analysis (table 1). Sediment samples from the three controlled run sites were similar in particle size distribution (table 2). In general, the study site shoreline sediments are predominantly medium sands and can best be described as unconsolidated, non-cohesive, sandy alluvium (figure 5). Sediment particle size analysis suggests that, because very little clay and silt size particles were present at any of the sites, shoreline sediments resuspended in the water column would be redeposited soon after the wave energy responsible for mobilization was dissipated or removed.

Maximum wave heights ranged from 0 to 1.64 feet at Gage 1 (shallow water) and from 0 to 0.80 feet at Gage 2 (deep water) (figure 6). It was anticipated that Gage 1 would measure higher maximum wave heights than Gage 2 because of its nearshore location. Waves tend to build higher crests as they start to interact with the river bottom. Wave height continues to build as they propagate shoreward until the wave finally breaks and expends its energy on the beach. This situation was observed at one controlled run site (Picnic Island Site 7). At the other two sites, shallow water maximum wave heights were not always higher than deep water maximum wave heights. Picnic Island did have a slightly steeper bottom gradient than the other two sites (figure 7). Measurement of the maximum wave height at a nearshore gage is confounded by the gage's location in relation to the height of the maximum wave height (which varies per run) and slope of the river bottom. Overall, deep water (Gage 2) maximum wave height readings are more consistent, not complicated by river bottom/wave interactions and may be more representative of the waves generated for each controlled run.

In general, maximum wave heights at both gages increased with increasing boat speed from 0 to 10 mph. At boat speeds 10 mph or greater, the particular boat we were using to generate waves began to plane and the resulting maximum wave heights did not continue to increase in size (figure 8). It should be noted that controlled run boat velocities used to generate the waves were less than 10 mph for 20 of the 23 runs (figure 9). Recreational boats with a planing hull design

and adequate horsepower will begin to plane and displace less water once adequate speed is attained, resulting in a reduction in the maximum wave height generated. Some recreational boats, however, do not plane but simply displace more water with increasing speed, resulting in larger maximum wave heights with increasing speed.

A close review of the number of waves in the wave train compared to boat velocity suggests that with increasing speed the number of waves contained within a wave train increases abruptly from no waves to nearly 40 small waves (figure 10). As both boat speed and maximum wave heights increase, the number of waves generally decreases. The maximum wave heights continue to increase in size until planing speed is reached and then smaller, but a larger number of waves, are generated.

The number of waves in each controlled run wave train ranged from 0 to 37 with a mean of 11 waves (figure 11). Wave trains continued for 0 to 31 seconds after each pass. Both of these wave train characteristics are similar to those measured by the Illinois State Water Survey (Bhowmik, 1992) during their 246 controlled runs on the Mississippi and Illinois Rivers. Graphing wave height to wave number on logarithmic scales suggests an inverse relationship (figure 12).

A comparison of maximum wave heights to the amount of sediment collected in the sediment traps after each controlled run was used to determine if an erosive energy threshold existed for the St. Croix River. Using maximum wave heights measured at the nearshore Gage 1, the sediment trap results indicate an erosive energy threshold at 0.4 feet. Similarly, a conservative interpretation of the Gage 2 results indicates a threshold for sediment mobilization at 0.4 feet (figures 13 and 14). Maximum wave heights less than the threshold value mobilized very small amounts of sediment (less than 1 gram/run) while maximum wave heights greater than the threshold values mobilized orders of magnitude greater amounts of sediment (as high as 405 grams/run were measured). See table 1 for the sediment trap values. Sediment traps with different orientations showed the same trends and the averages of the two traps were plotted for each controlled run for figures 13 and 14.

The data (figure 14) also suggests that wave trains associated with measured maximum wave heights greater than 0.7 feet (as measured at the deep water gage - Gage 2) may actually be affecting the sediment traps efficiency by either remobilizing sediment that had been deposited already within the sediment trap or by carrying a large amount of resuspended material out past the traps.

At boat velocities less than 5 mph, very little sediment was mobilized (figure 15). (In "Slow - No Wake Zones" motorboat operation is restricted to "the slowest possible speed necessary to maintain steerage, but in no case greater than 5 miles per hour"). Velocities greater than 5 mph, but less than planing velocity, showed a large increase in the amount of sediment mobilized. Once the boat was planing, increasing boat velocities had less of a tendency to mobilize sediments. When compared to the normal recreational boating activity that occurs within this reach of the St. Croix, the controlled run boat would be below average in size, horsepower and displacement. Controlled run velocities were much less than that of the majority of recreational boats using this reach of the river.

A plot of maximum wave height and maximum turbidity measured in ISCO water samples indicates increasing turbidity with increasing wave height (figure 16). Similarly, the Hydrolab water quality meter data indicates pre-controlled run (ambient) turbidities were always surpassed by turbidity measurements during the controlled run (figure 17).

Analysis of the erosion pin data was limited because of the highly variable nature of the data (table 3). When absolute change (erosion plus deposition) for all pins in a controlled run were summed and graphed, a best fit line suggests that increasing maximum wave heights result in greater changes in shoreline surface elevation (figure 18).

The sediment mobilization threshold determined by the controlled runs was compared to the theoretical threshold for sediment particles size 0.5 mm or less in 1 foot of water (Parchure et al. for WES, draft 1999). Based on equations contained within the WES document, a graph was produced which plotted maximum wave height threshold values against water depth (figure 19).

The controlled run mobilization threshold plotted just above the 0.278 pascal bed shear stress threshold line confirming the validity of the threshold determined in the field. It is hypothesized that the field determined threshold is slightly above the theoretical threshold because the sediment had to be resuspended above the 1.5 inch lip of the sediment trap before it was measured. Also implied by figure 19 is that large boat waves can mobilize nearshore sediments to depths as great as 5 feet.

DISCUSSION AND CONCLUSIONS

The results from all four techniques used in this study suggested a positive relationship between sediment mobilization and maximum wave height. In addition, the sediment trap results indicate a maximum wave height of 0.4 feet as the erosive energy threshold for beach and nearshore sands on the St. Croix River. Controlled runs at less than 5 miles per hour had maximum wave heights below the erosive energy threshold. High turbidity values were not sustained after passage of the wave train. Most redeposition occurs in the nearshore area because of the quick settling time of the sand size sediments.

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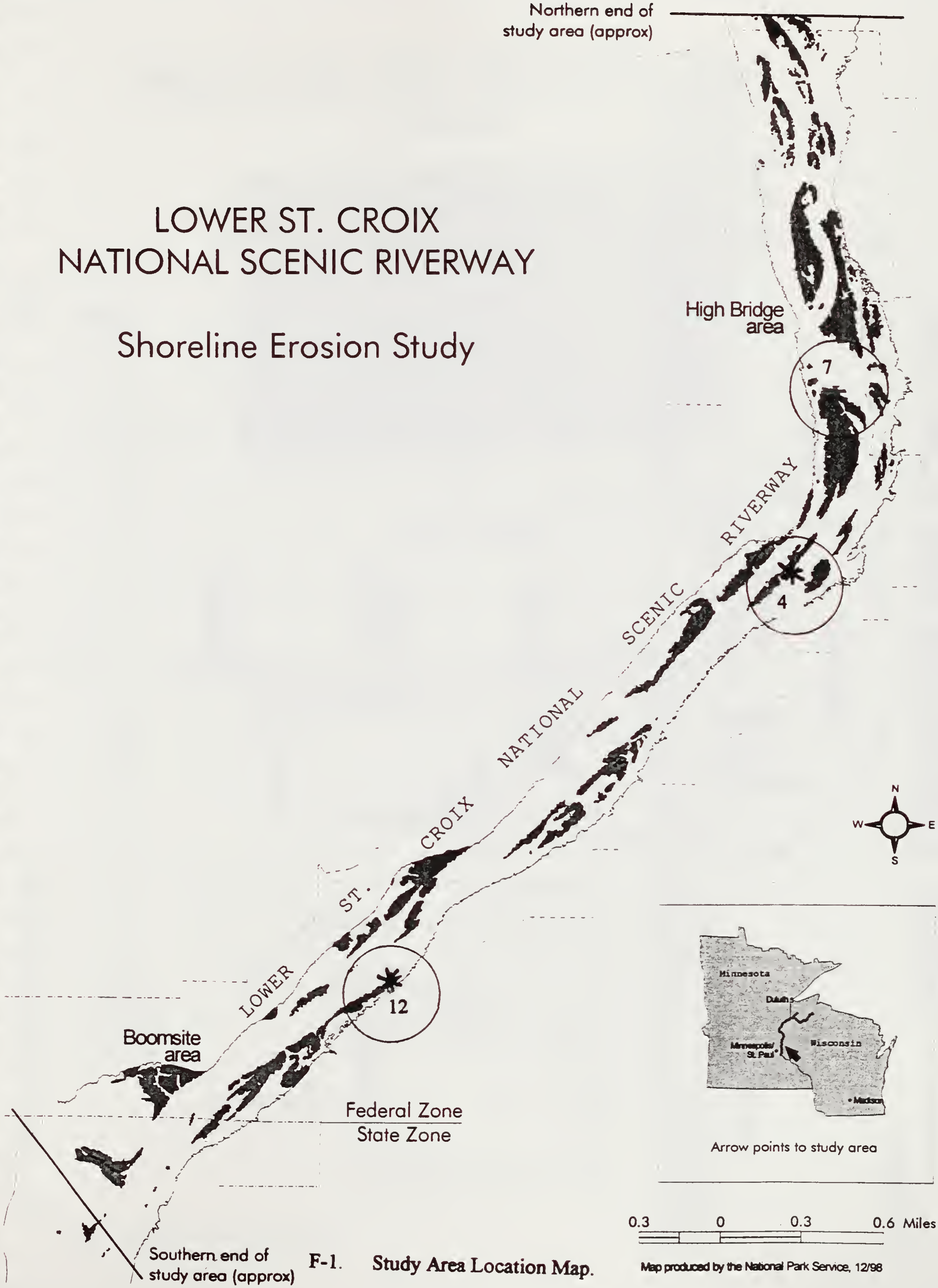
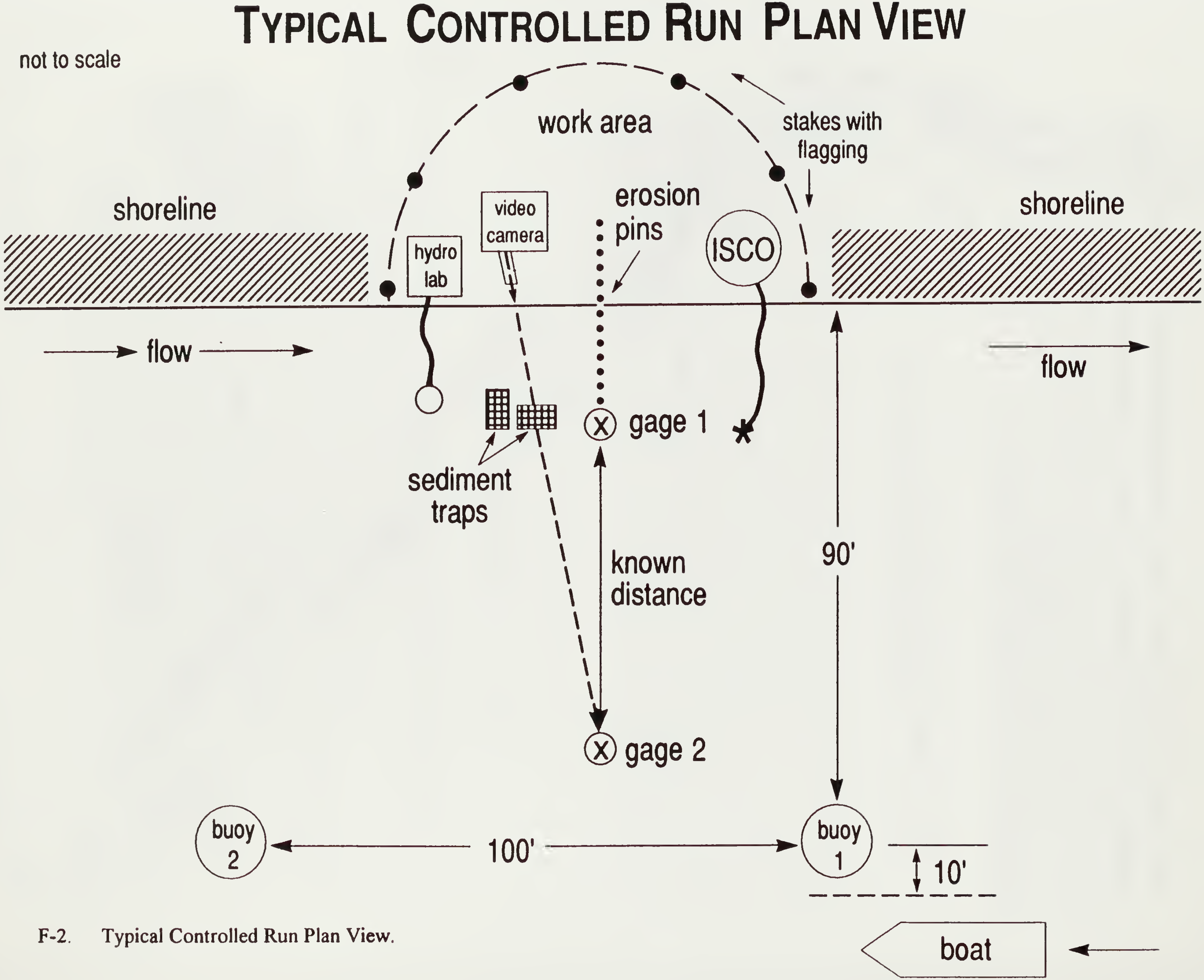


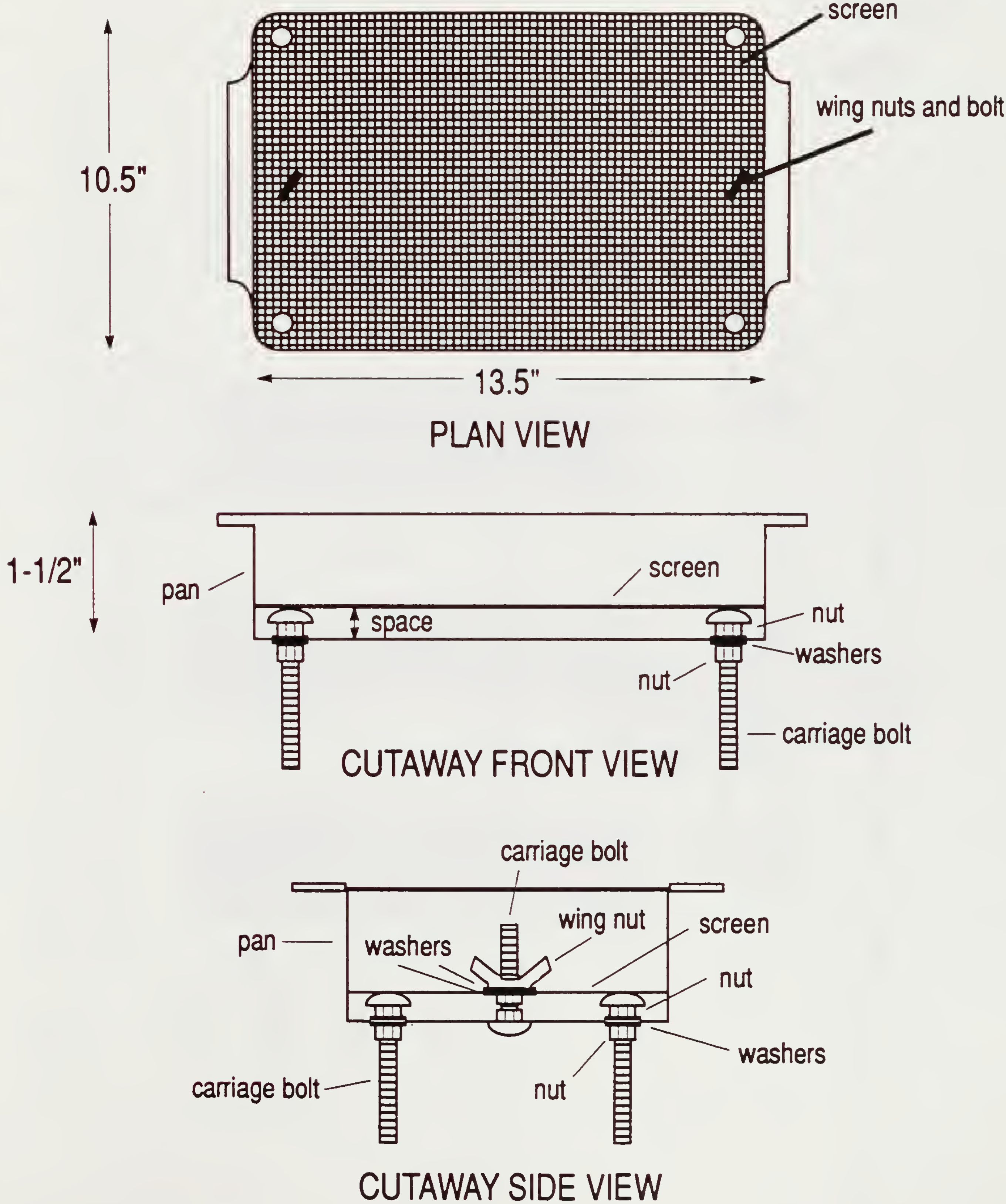
F-1. **Study Area Location Map.**



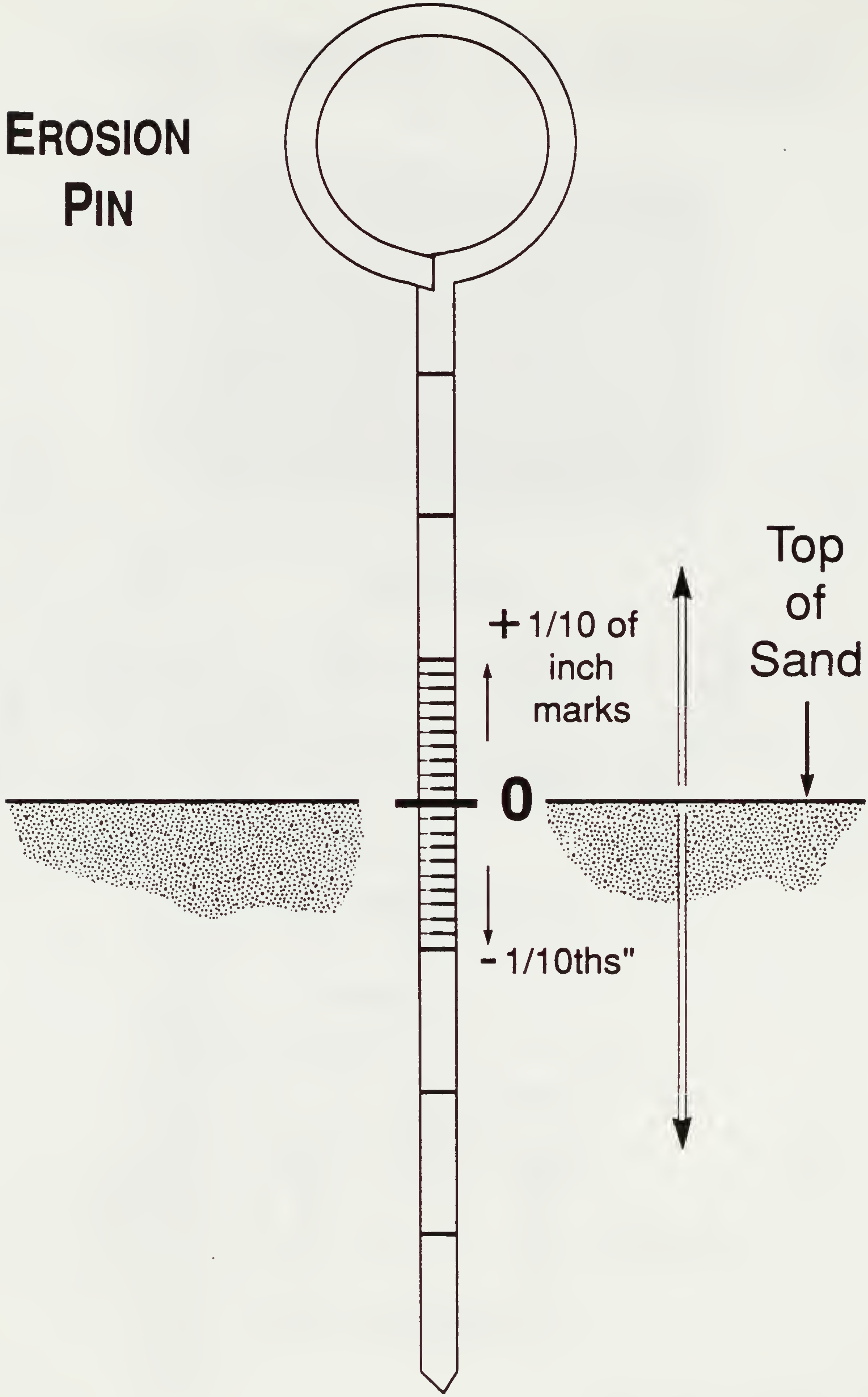
F-2. Typical Controlled Run Plan View.

Prototype For Sediment Trap

(not to scale)



F-3. Sediment Trap Diagram.



F-4. Erosion Pin Diagram.

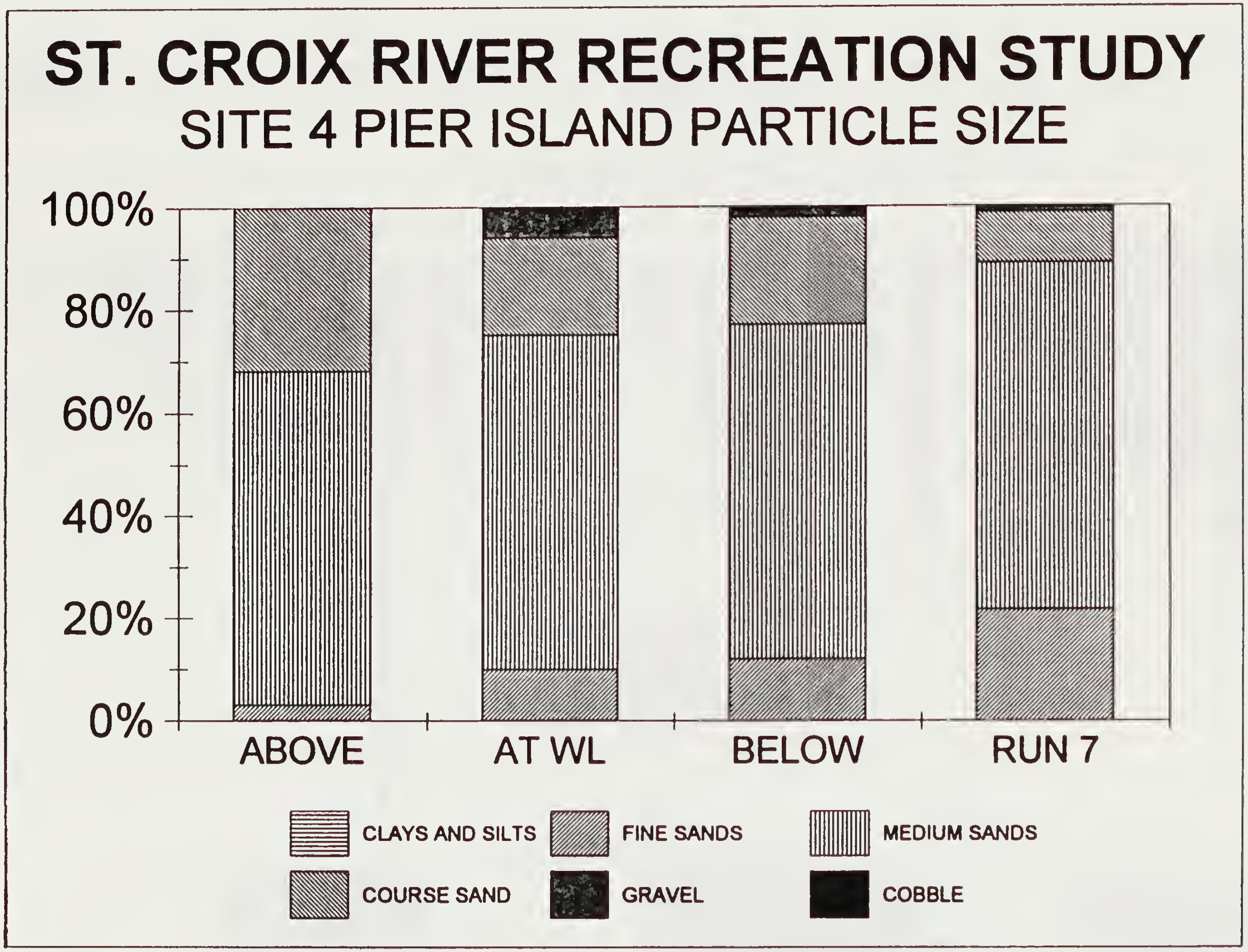
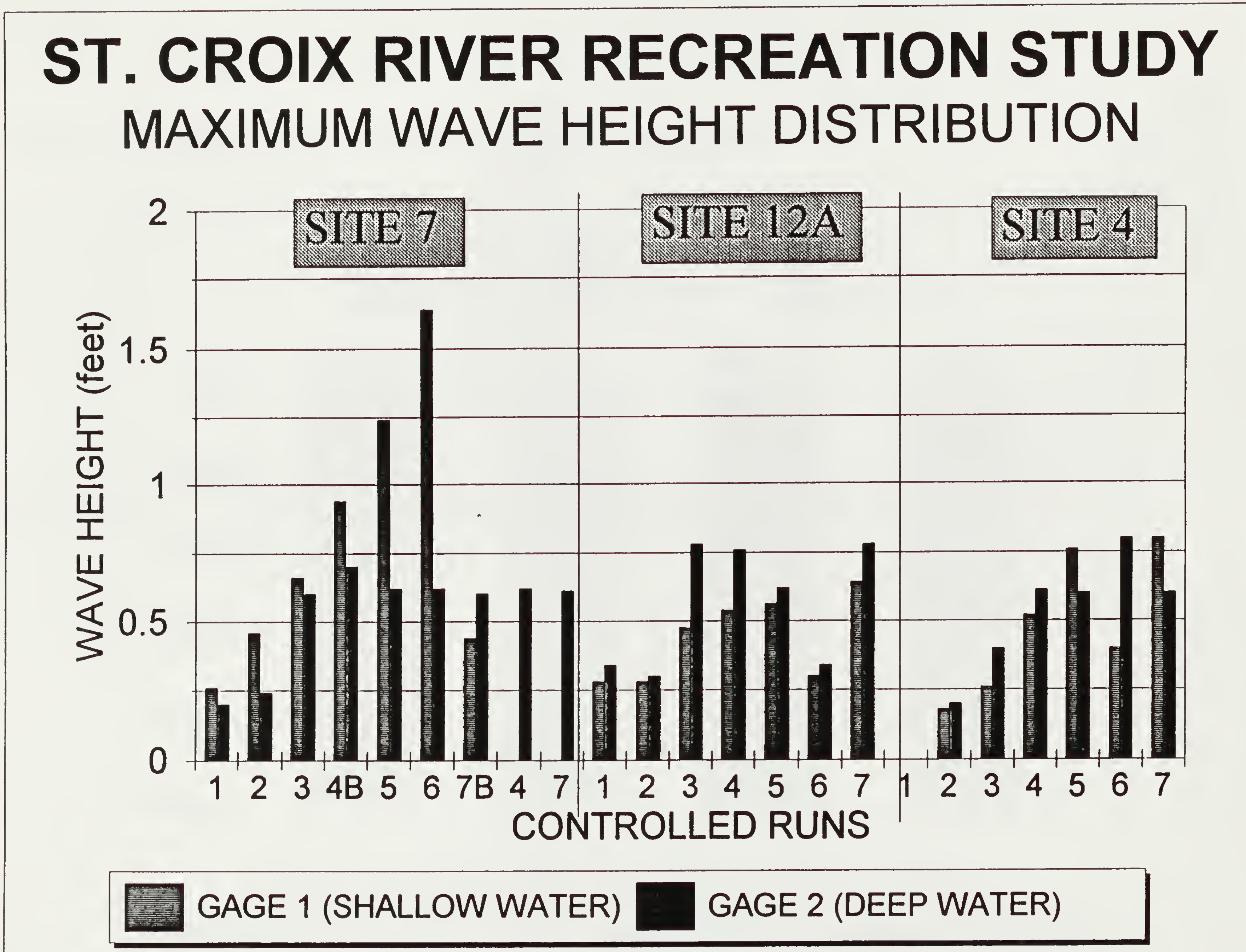
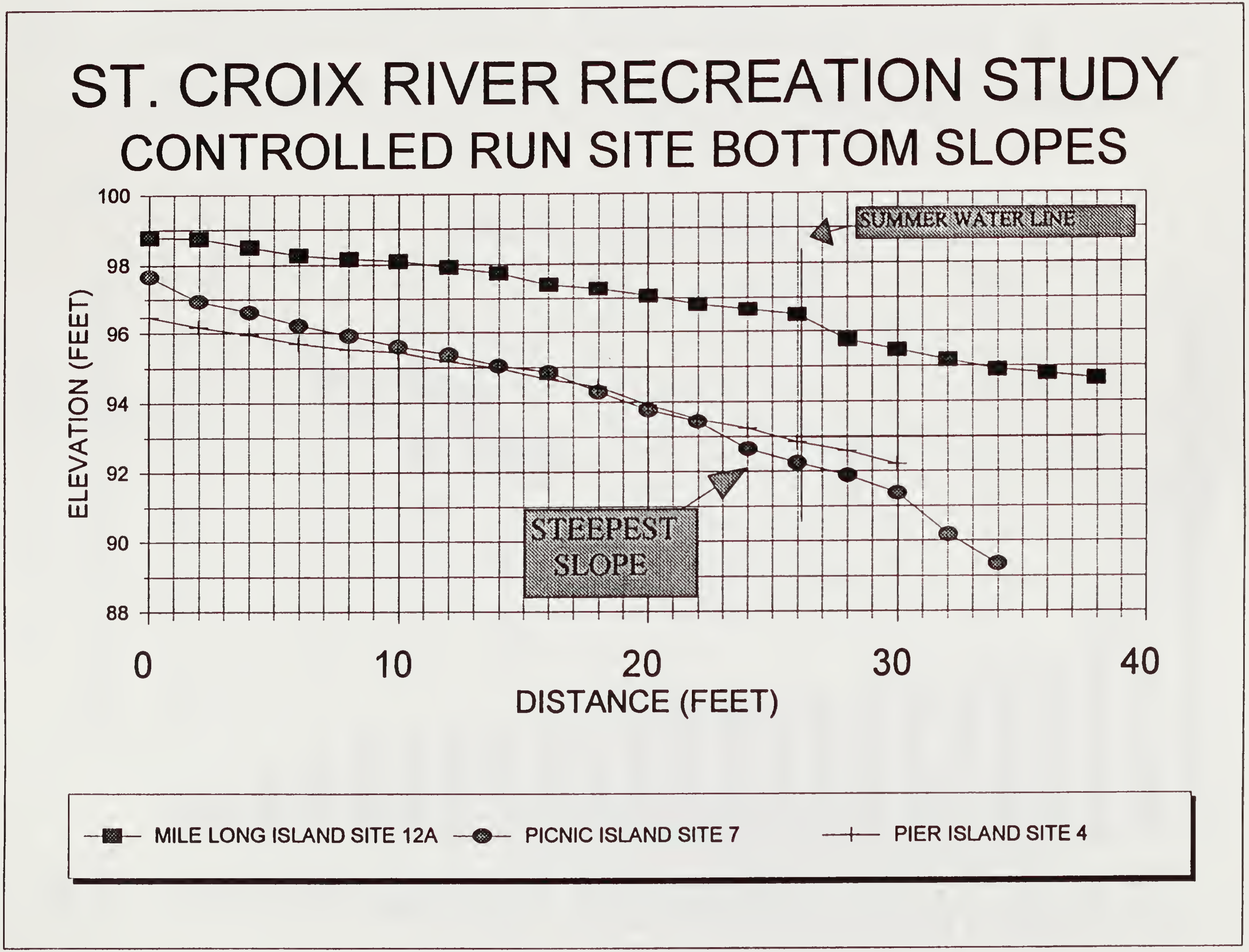


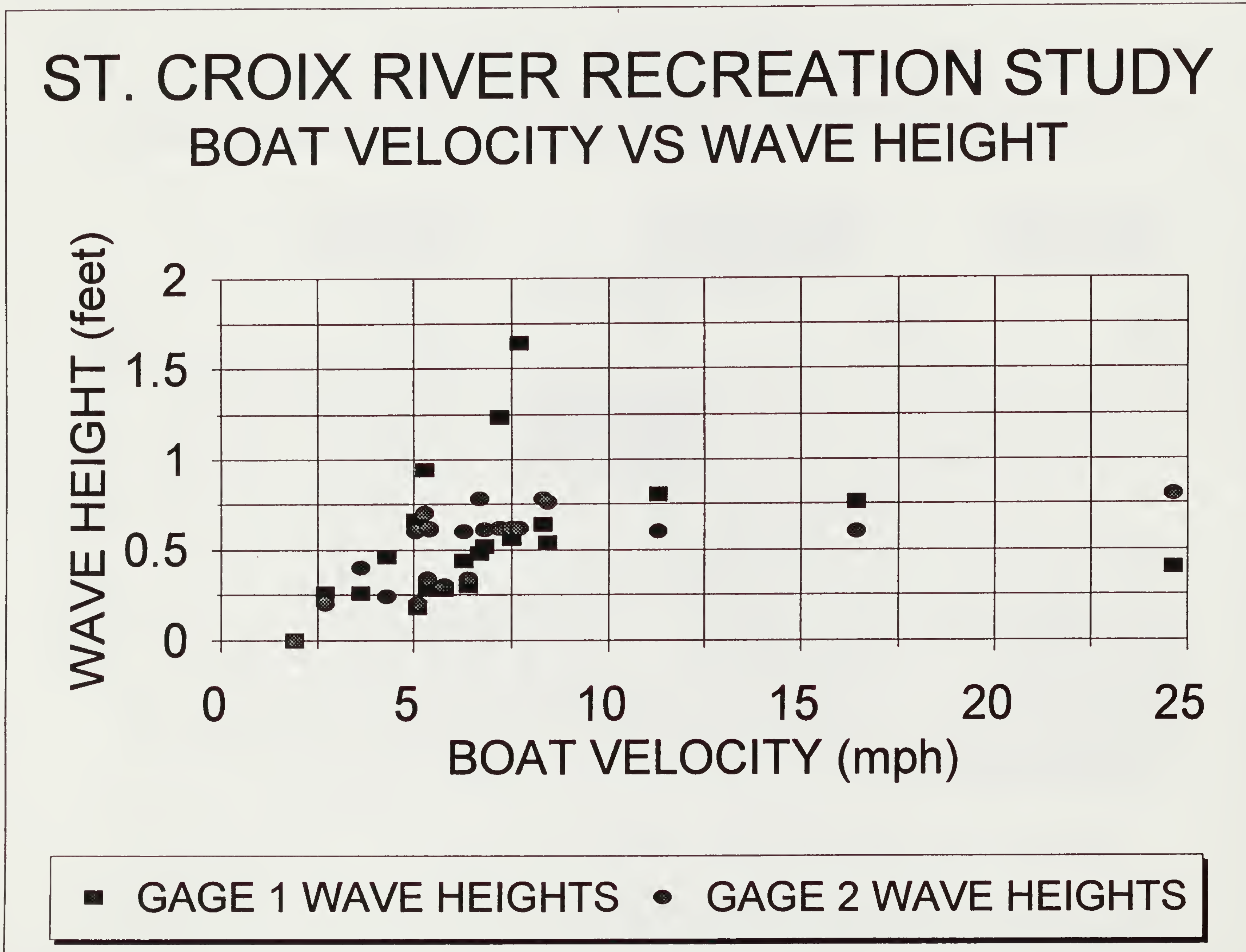
FIGURE 5. SEDIMENT PARTICLE SIZE DISTRIBUTION AT PIER ISLAND.



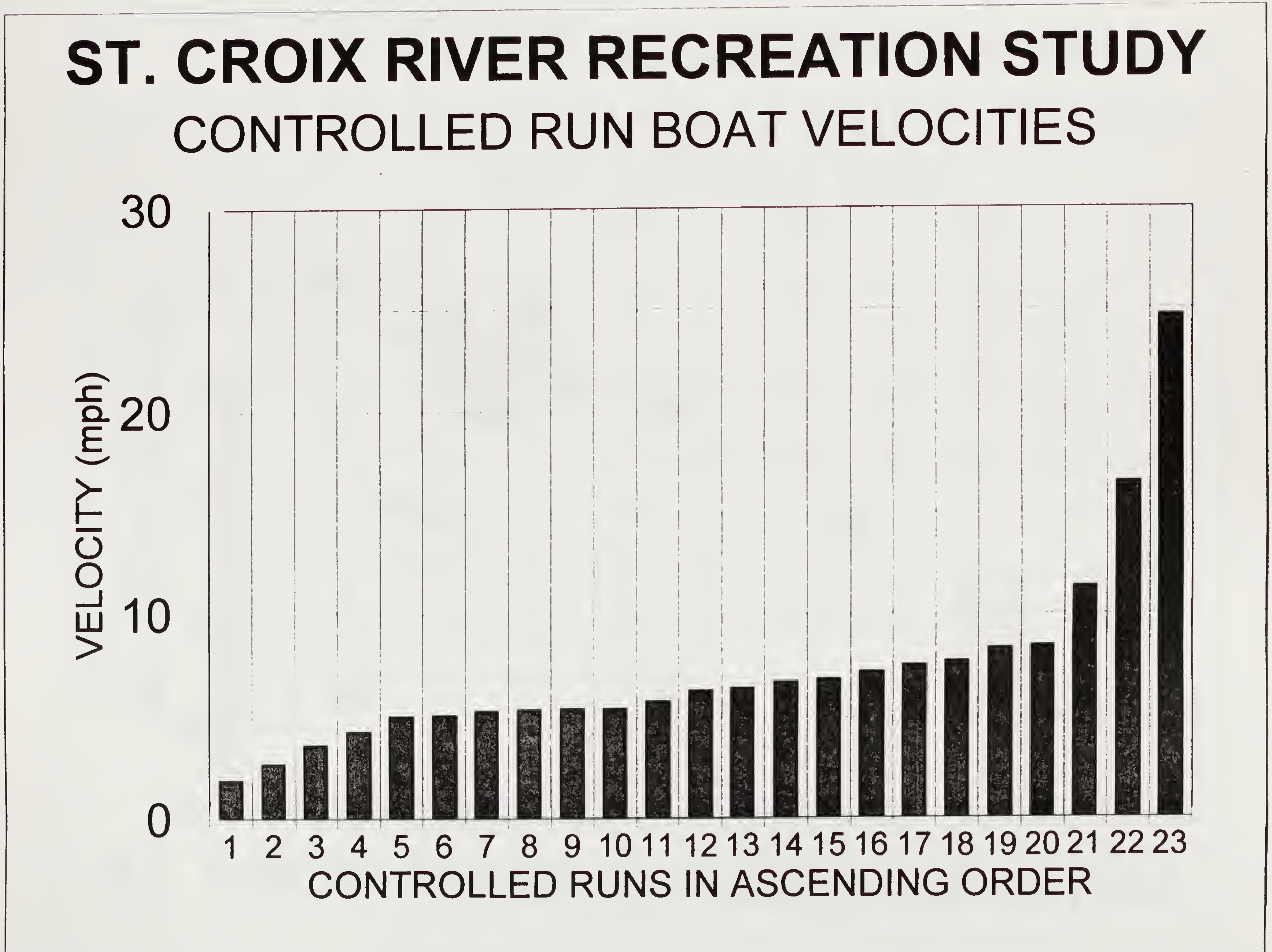
F-6. Maximum Wave Height Distribution.



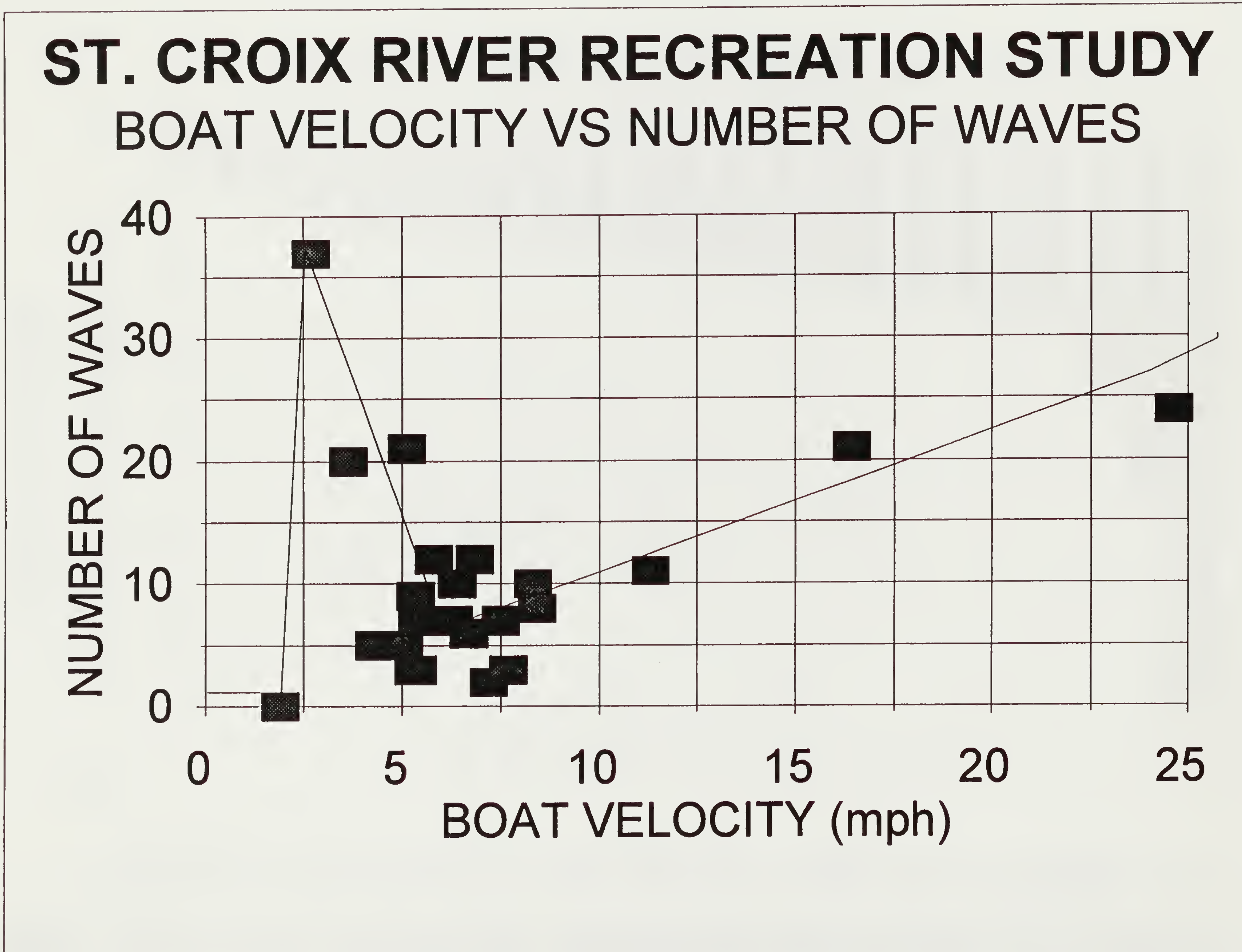
F-7. Controlled Run Bottom Slopes.



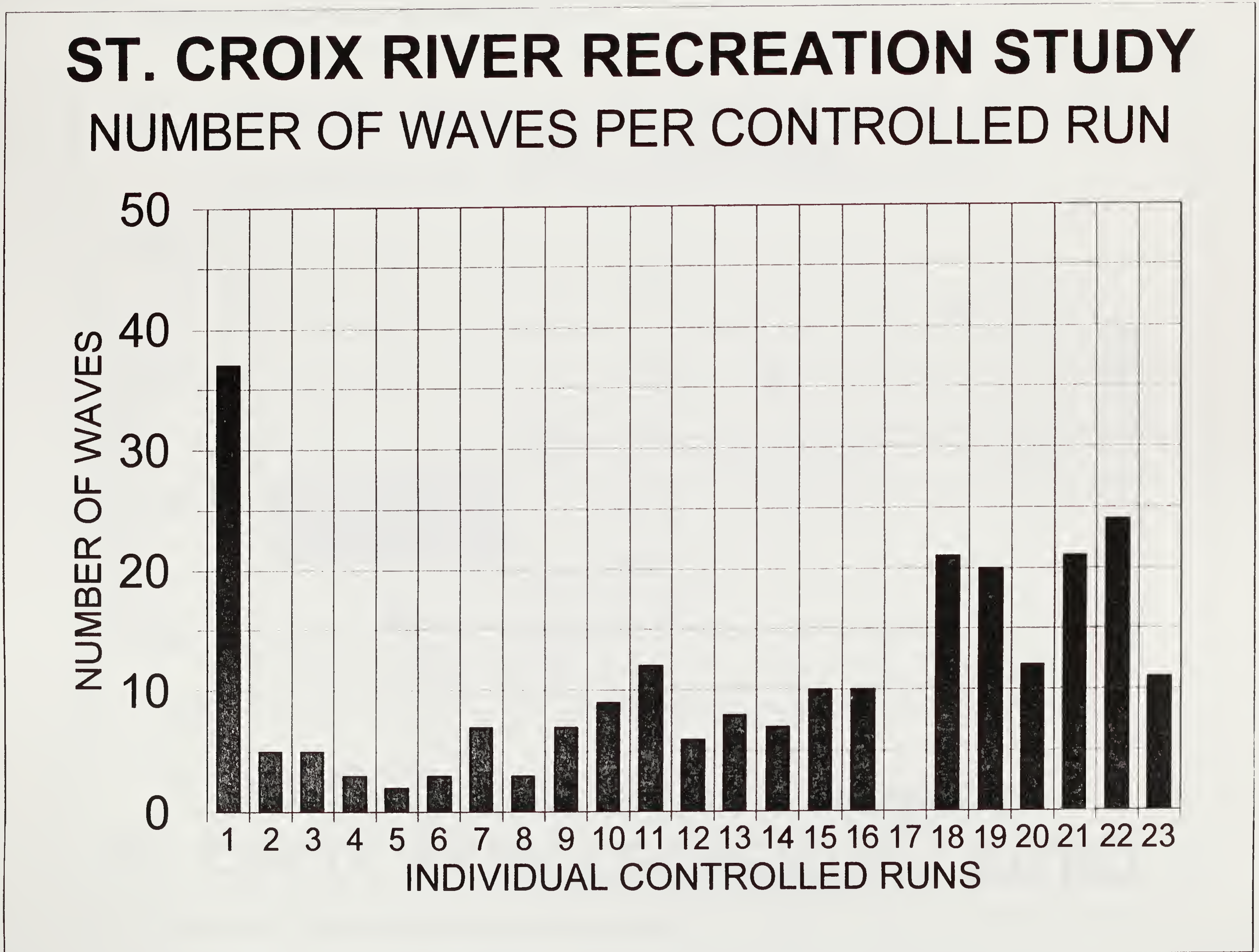
F-8. Boat Velocity vs Maximum Wave Height.



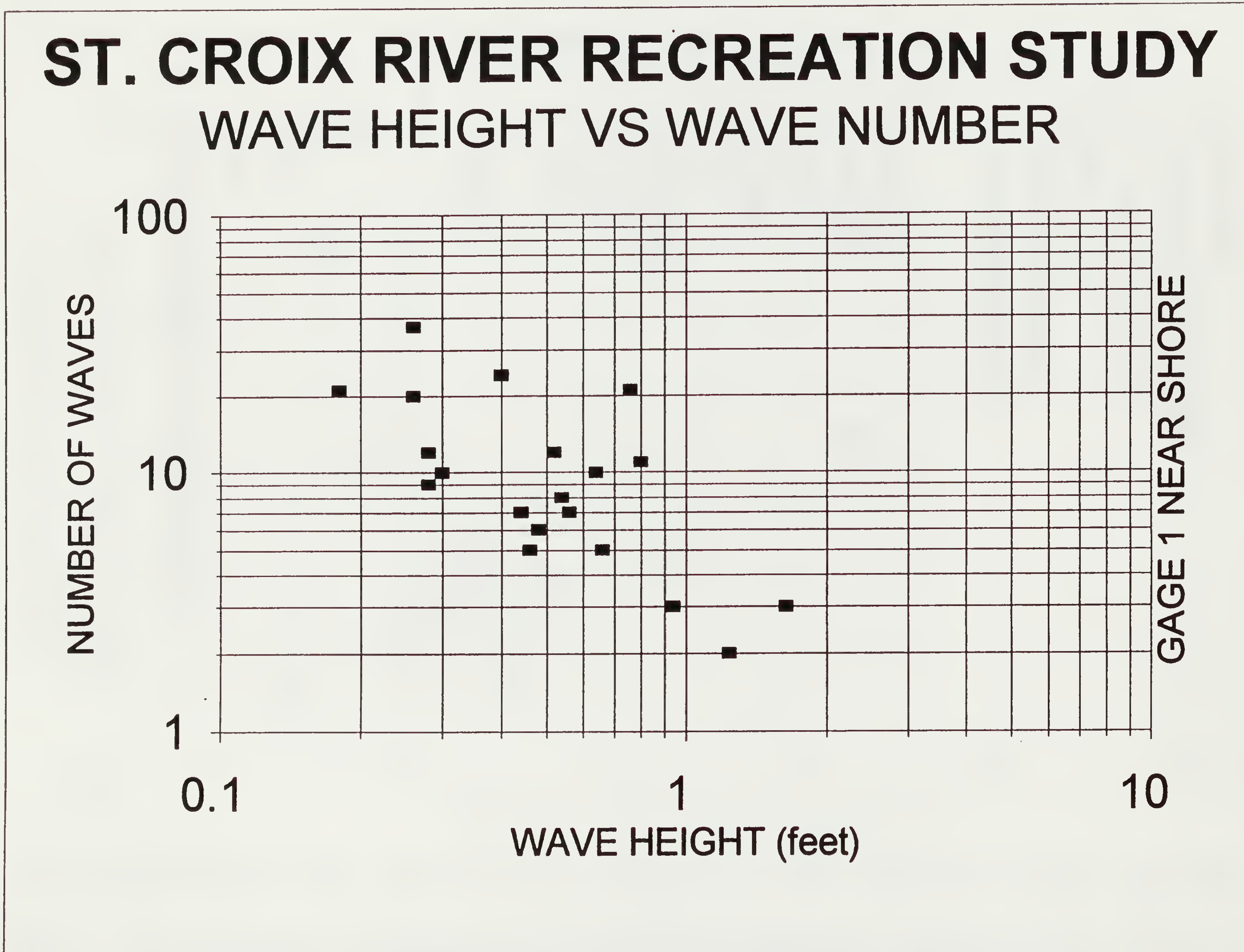
F-9. Controlled Run Boat Velocities.



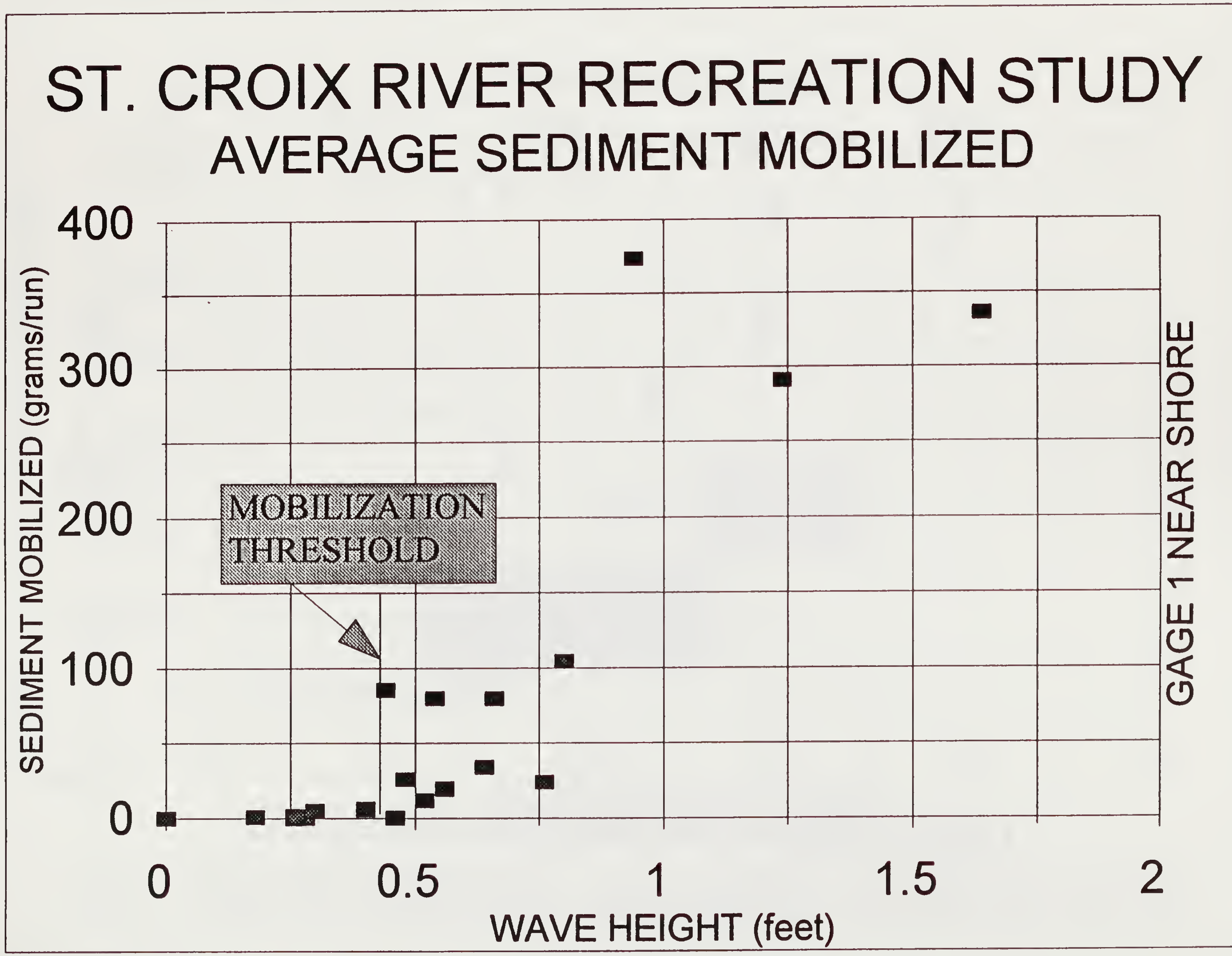
F-10. Boat Velocity vs Number of Waves in a Wave Train.



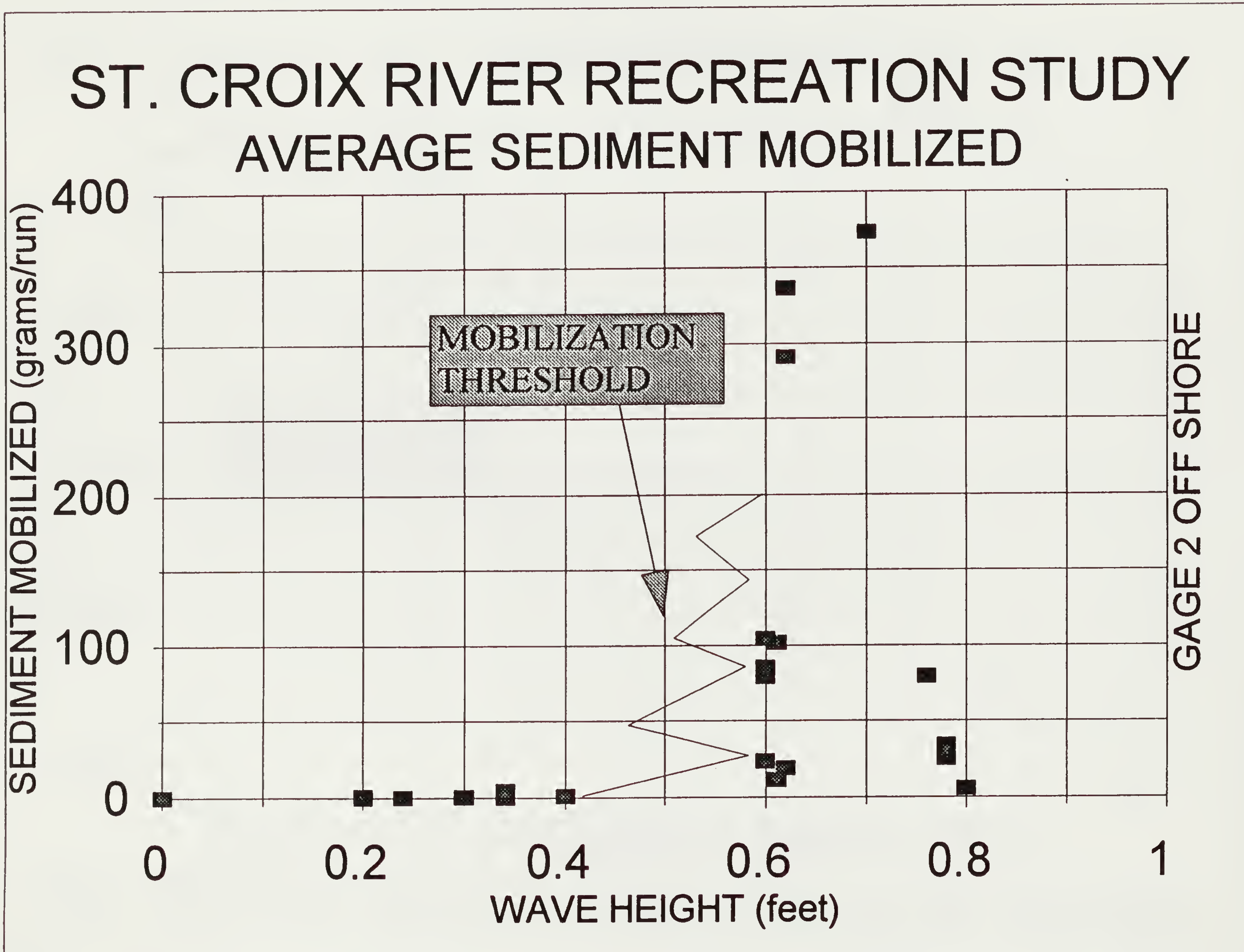
F-11. Number of Waves per Controlled Run.



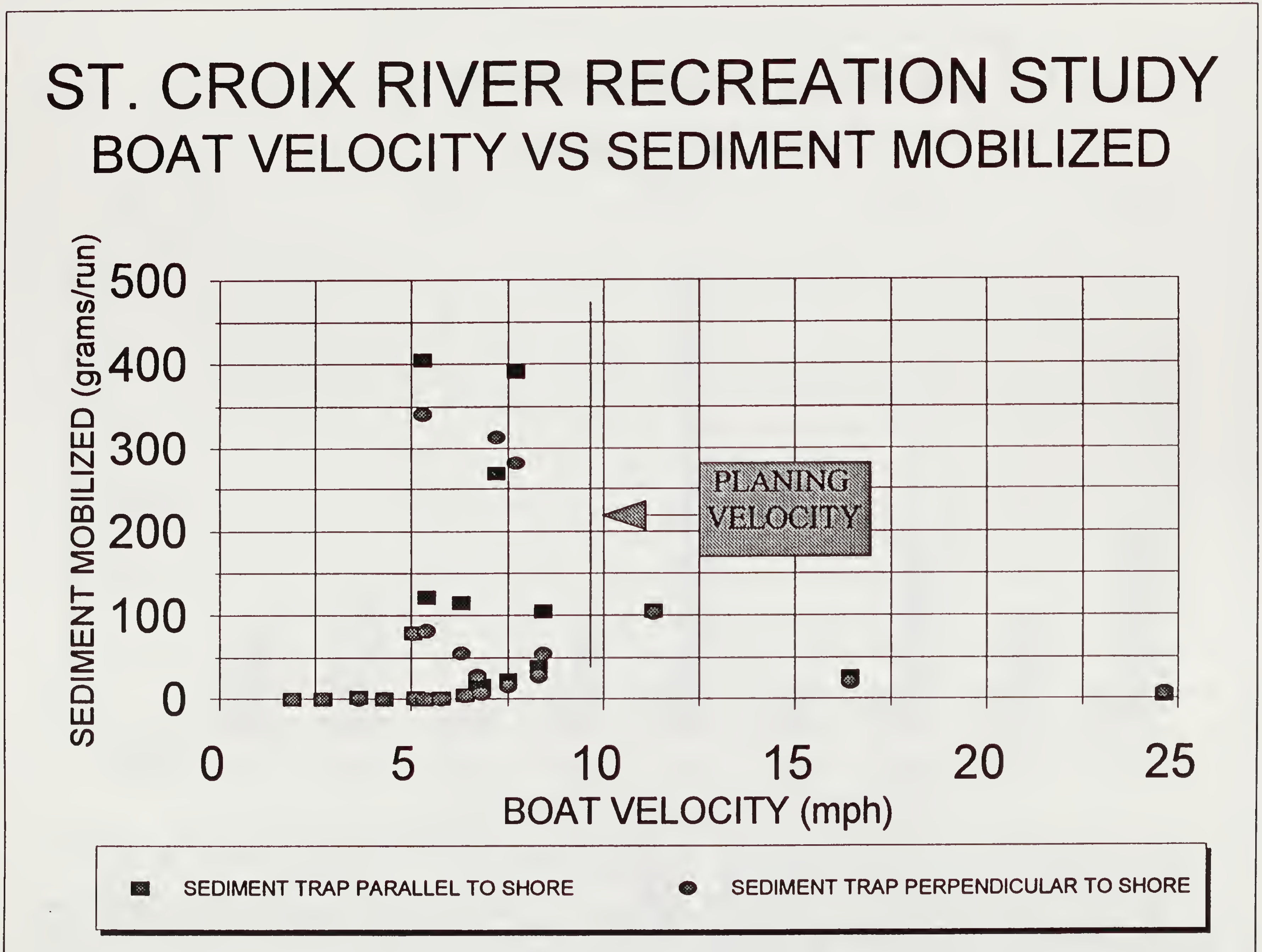
F-12. Maximum Wave Height vs Wave Number Log Log Plot



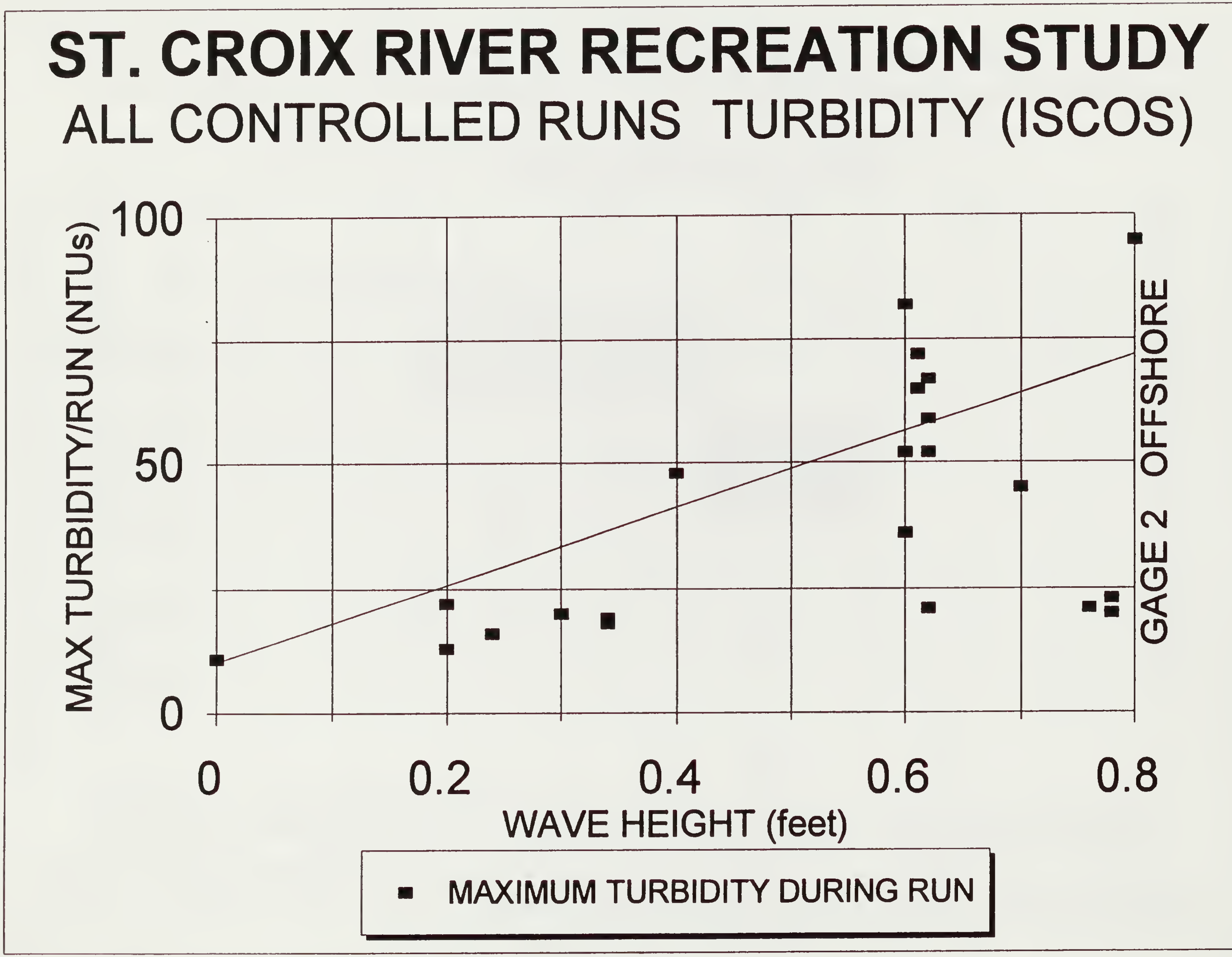
F-13. Maximum Wave Height vs Average Sediment Mobilized.(Gage 1).



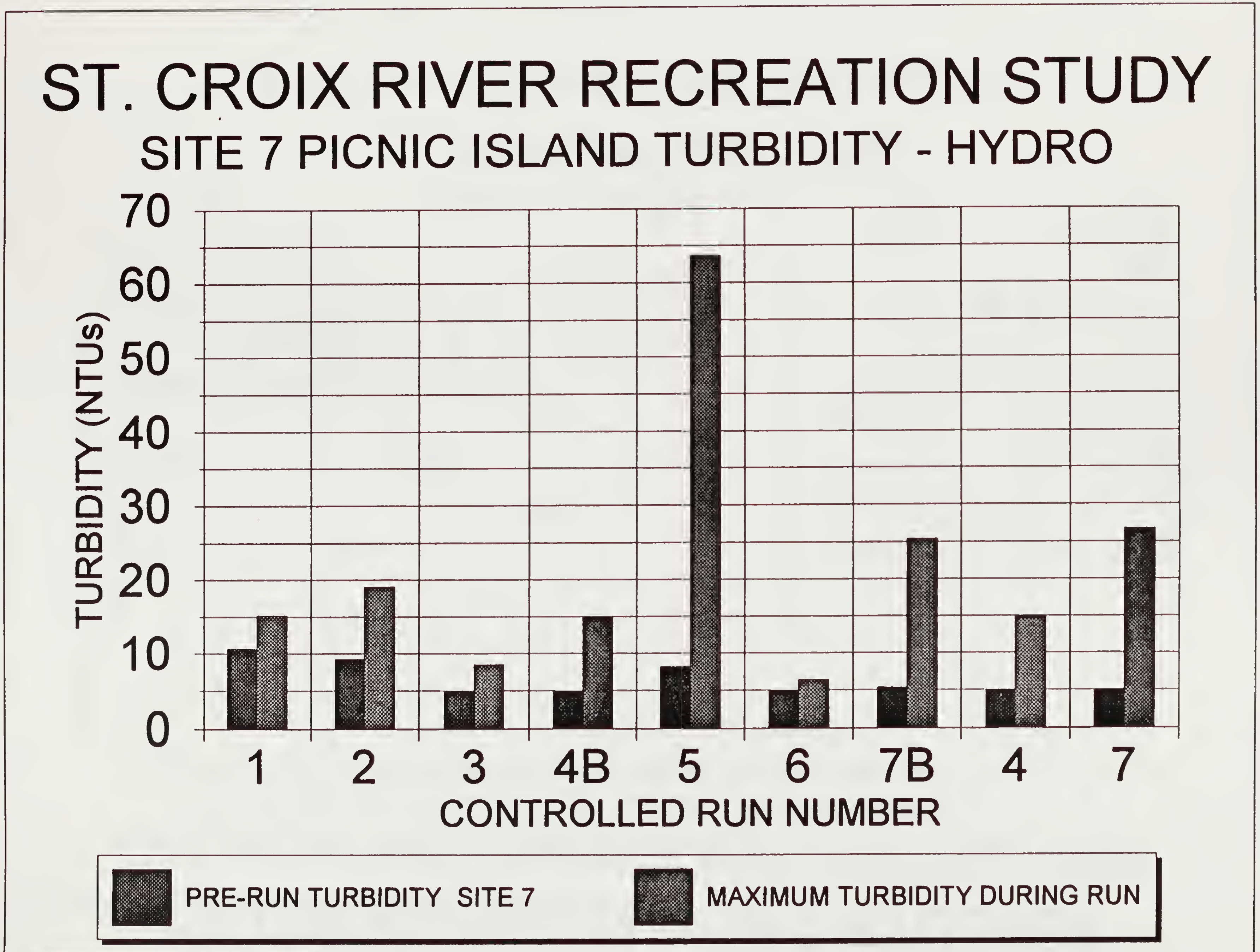
F-14. Maximum Wave Height vs Average Sediment Mobilized (Gage 2).



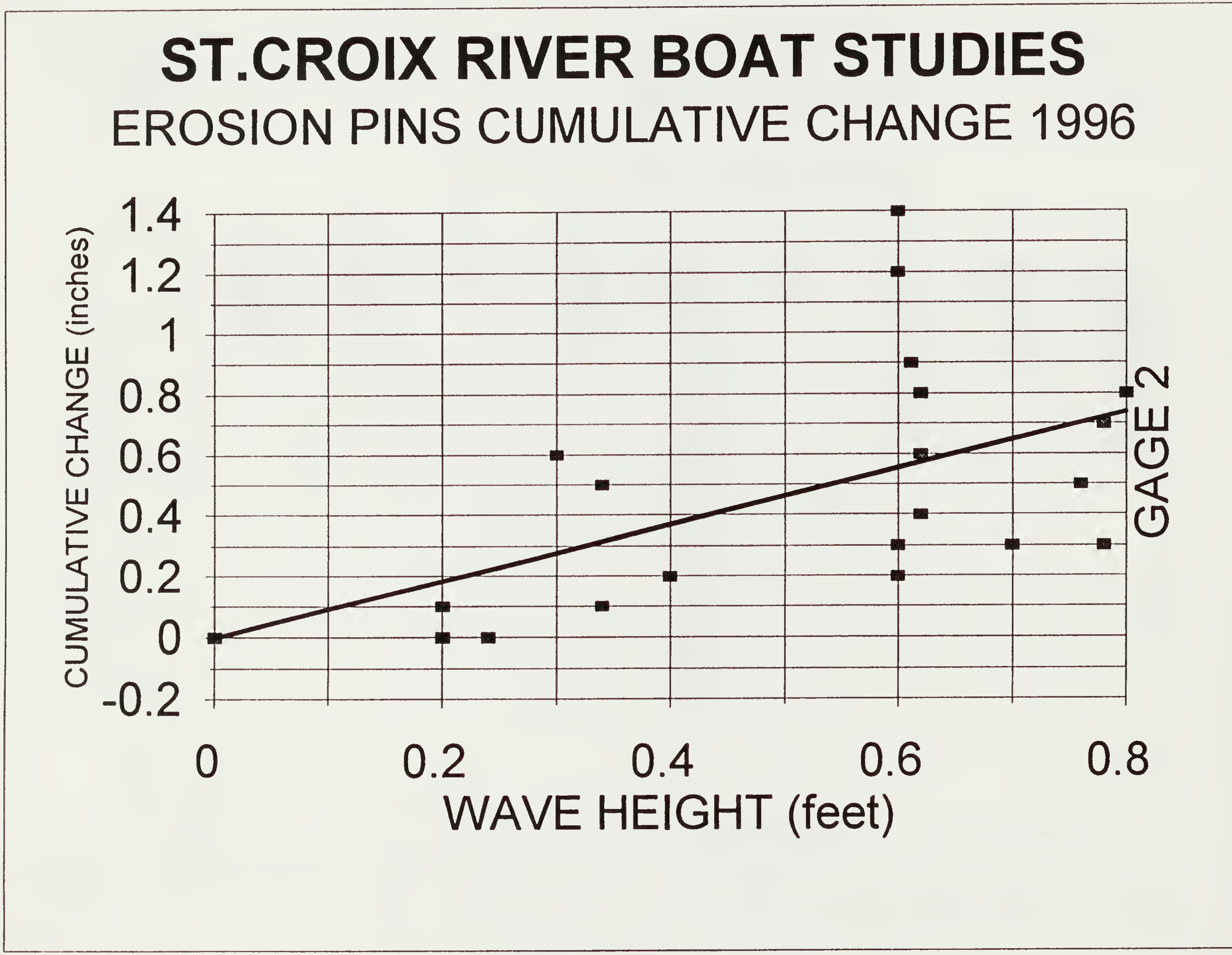
F-15. Boat Velocity vs Sediment Mobilized.



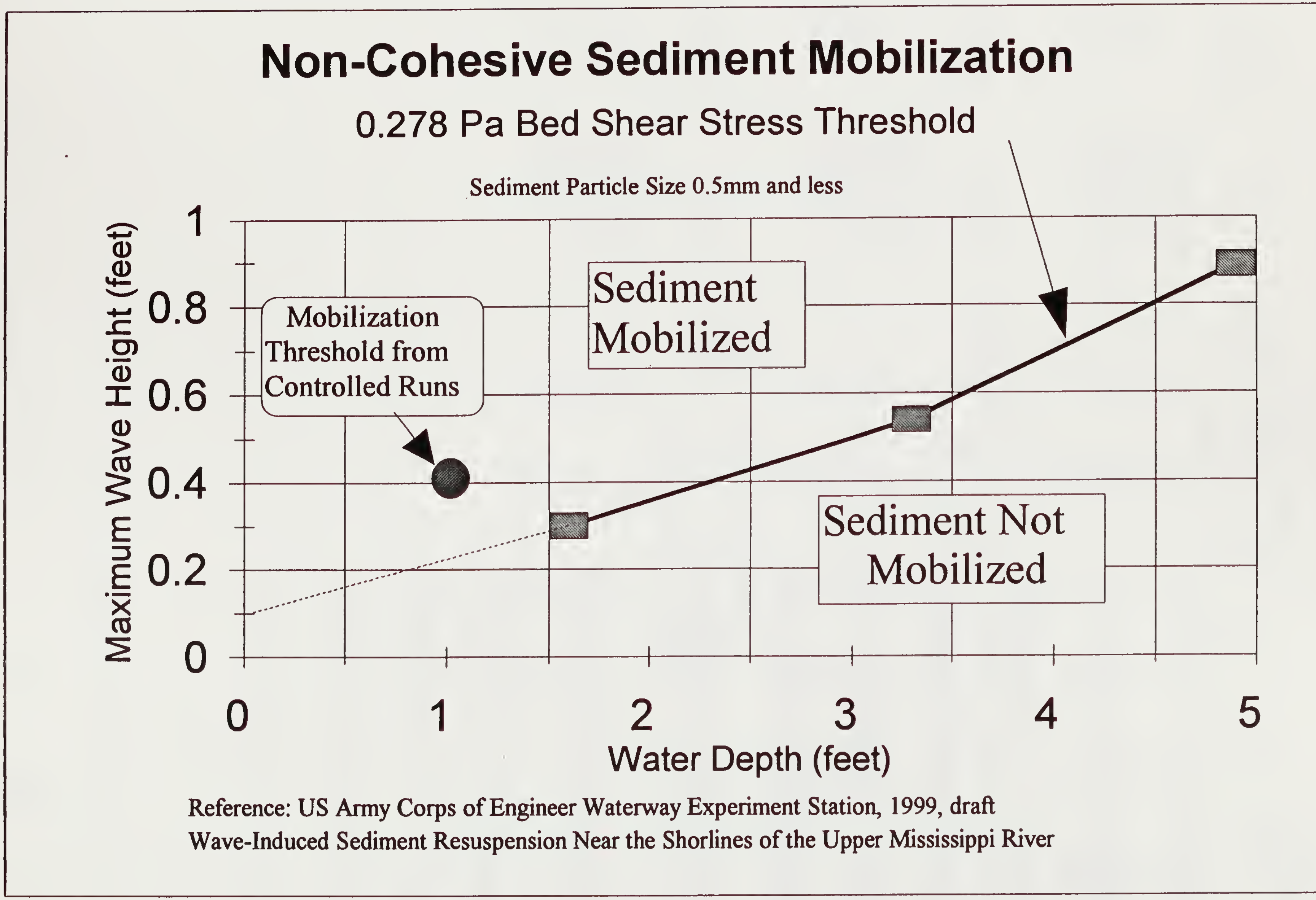
F-16. Maximum Wave Height vs Maximum Turbidity (ISCOs).



F-17. Pre Run Turbidity vs Maximum Controlled Run Turbidity (Hydrolab).



F-18. Maximum Wave Height vs Erosion Pin Cumulative Change.



F-19. Sediment Mobilization Theoretical Threshold.

ST. CROIX RIVER RECREATIONAL BOATING CONTROLLED RUNS

		RUN NUMBER	BOAT VELOCITY FT/SEC	BOAT VELOCITY MPH	TOTAL NUMBER WAVES	WAVE TRAIN TIME	WAVE PERIOD T (WAVES/SEC)	WAVE FREQ L (SEC/WAVE)	WAVE CELERITY FT/SEC	GAGE 1 WAVE MAX	GAGE 2 WAVE MAX	SED TRAP grams/ft2 PARALLEL	SED TRAP gram/ft2 NORMAL	ISCO CONTROLLED RUN TURBIDITY	HYDROLAB TURBIDITY BEFORE	HYDROLAB TURBIDITY MAX
SITE 7 7/25/96 PICNIC ISLAND	1	1	3.92	2.70	37.00	25.00	1.48	0.68	2.24	0.00	0.00	0.30	0.10	13	10.80	15.20
	2	2	8.34	4.30	5.00	9.78	0.51	1.96	7.14	0.26	0.20	0.30	0.10	18	9.20	19.10
	3	3	7.41	5.05	5.00	10.94	0.46	2.19	7.85	0.26	0.40	2.80	0.30	36	5.00	8.50
	4	4B	7.79	5.30	3.00	8.03	0.37	2.68	6.04	0.46	0.24	0.20	0.80	45	5.00	14.80
	5	5	10.53	7.20	2.00	4.18	0.48	2.08	7.58	0.66	0.80	80.00	79.00	59	8.20	63.80
	6	6	11.24	7.70	3.00	8.12	0.49	2.04	7.85	0.18	0.20	2.10	0.30	52	5.00	8.40
	7	7B	9.22	8.30	7.00	14.31	0.49	2.04	7.14	0.94	0.70	405.00	342.00	52	5.40	25.40
	8	4	7.97	5.40	3.00	8.20	0.37	2.73	NA	0.28	0.34	0.40	0.40	87	5.00	14.80
	9	7	7.98	5.40	7.00	12.90	0.54	1.84	11.21		0.61	122.00	82.20	65	5.00	26.80
SITE 12A 9/19/96 MILE LONG ISLAND	10	1	7.75	5.35	9.00	12.00	0.75	1.33	3.50		0.82	NA	NA	18		
	11	2	8.40	5.80	12.00	17.00	0.71	1.42	1.87	0.28	0.30	1.20	0.30	20		
	12	3	9.71	8.70	8.00	12.00	0.50	2.00	4.66	0.44	0.60	115.00	56.00	20		
	13	4	12.20	8.42	8.00	14.00	0.57	1.75	5.17	0.30	0.34	5.80	4.00	21		
	14	5	10.87	7.50	7.00	13.00	0.54	1.86	NA	0.48	0.78	21.70	29.40	21		
	15	6	9.26	6.40	10.00	18.00	0.83	1.80	3.30	0.52	0.81	18.80	8.80	19		
	16	7	12.05	8.31	10.00	18.00	0.63	1.80	8.47	1.24	0.82	269.00	314.00	23		
SITE 4 9/19/96 PIER ISLAND	17	1	2.77	1.91	0.00	0.00			0.00	0.56	0.82	23.30	15.50	11		
	18	2	7.42	5.12	21.00	30.00	0.70	1.43	2.78	1.64	0.82	391.00	282.00	22		
	19	3	5.26	3.63	20.00	26.00	0.77	1.30	3.70	0.64	0.78	39.70	28.30	48		
	20	4	9.90	8.83	12.00	25.00	0.48	2.08	4.83	0.54	0.78	104.80	55.20	72		
	21	5	23.81	18.43	21.00	31.00	0.68	1.48	7.17	0.80	0.60	105.30	103.40	82		
	22	6	35.71	24.64	24.00	31.00	0.77	1.29	8.92	0.78	0.80	27.80	20.20	95		
	23	7	16.40	11.32	11.00	20.00	0.55	1.82	6.87	0.40	0.80	4.00	8.10	280		

T-1. Controlled Run Wave Characteristics and Data Sets.

SEDIMENT CUMMULATIVE FREQUENCY CURVES
ST. CROIX RIVER CONTROLLED RUNS

SITE 4 PIER ISLAND

SCREEN MESH SIZE	PARTICLE SIZE	SCREEN NO	CUM % ABOVE	CUM % AT WL	CUM % BELOW	CUM % RUN 7	ISCO
0	SILTS /CLAYS		0	0	0	0	0
0.0049	FINE SAND	120	3	10	12	21.8	14
0.0098	MED SAND	60	68	75	77	89.8	86
0.0197	COURSE SAND	35	100	94	98	98.8	93
0.0787	GRAVEL	10	100	100	100	99.8	100
0.1			100	100	100	100	100

SITE 12A MILE LONG ISLAND

SCREEN MESH SIZE	PARTICLE SIZE	SCREEN NO	CUM % ABOVE	CUM % AT WL	CUM % BELOW	CUM % RUN4
0	SILTS /CLAYS		0	0	0	0
0.0049	FINE SAND	120	6.8	4.6	8	2.7
0.0098	MED SAND	60	69.8	46.6	47	75.7
0.0197	COURSE SAND	35	99.8	99.6	97	99.7
0.0787	GRAVEL	10	100	100	100	100
0.1			100	100	100	100

SITE 7 PICNIC ISLAND

SCREEN MESH SIZE	PARTICLE SIZE	SCREEN NO	CUM % ABOVE	CUM % AT WL	CUM % BELOW
0	SILTS /CLAYS		0	0	0
0.0049	FINE SAND	120	1	1	3
0.0098	MED SAND	60	26	27	29
0.0197	COURSE SAND	35	81	97	80
0.0787	GRAVEL	10	98	100	98
0.1			100	100	100

T-2. Sediment Particle Size Distribution.

EROSION PIN DATA SUMMER 1996

	PIN POSITION	SITE 7 PICNIC ISLAND RUN 1	RUN 2	RUN 3	RUN 4	RUN 4B	RUN 5	RUN 6	RUN 7	RUN 7B	SITE 4 PIER ISLAND RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7	SITE 12A MILE LONG ISLAND RUN 1	RUN 2	RUN 3	RUN 4	RUN 5	RUN 6	RUN 7
	10	0	0	0	0	0	0	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0
	9	0	0	0	0	-0.1	0	0	0.1	0	0	0	0	0		0	0	0	0	0		0	0	0
	8	0	0	0	0	-0.1	0.2	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0
	7	0	0	0	0.2	0	0.2	0	0	0	0	0	0	0		0	0	0	0	0		0	0	0
	6	0	0	0	0	0	0	0.1	0	0	0	0	0	0		0	0	0	0	0		0	0	0
	5	0	0	0	0	0	0	0.1	0.1	0	0	0	0	0		0	0	0	0	0		0	0	0
	4	0	0	0	0	0	0.1	0.1	0.1	0	0	0	0	0		0	0	0	0	0		0	0	0
LAND	3	0	0	0	0	-0.1	0	0.1	0	0	0	0	0	0		0.1	-0.1	0	0	0		0	0	0
WARD	2	0	0	0	0.2	0	0.2	0	0	-0.1	0	0	0	-0.1		0.1	-0.2	0	0	0		0	0	0
	1	-0.1	0	-0.1	0.1	0	0	-0.1	0.1	-0.3	0	0	0.2	0.1		-0.1	-0.2	-0.1	0	0		0	-0.1	0
WATERS	0	0	0	-0.1	0.1	0	0.1	-0.1	0	-0.1	0	0	0	0.3		0	-0.1	0	0	-0.1		0	0	0
EDGE	-1	NM	NM	NM	NM	NM	NM	NM	0	-0.2	0	0	0	0.2		-0.2	0	0	0	-0.1		0	0	0
	-2								-0.2	-0.3	0	0	0	0		0.1	0.2	0	-0.1	0.1		0	0	0
WATER	-3								-0.1	-0.3	0	0	0	-0.2		0	0	-0.1	-0.1	0.1		0	0	0.1
WARD	-4								0	0	0	0	0	0	END	-0.1	0	-0.1	-0.2	0	END	0	0	-0.2
	-5								0	-0.1	0	0	0	0	0	0	-0.2	-0.1	0	0	-0.1	0	0	0
	-6									0	0	0	0	0	-0.2	0	-0.1	0	-0.1	0	-0.1	-0.2	0	0
	-7										0	0	0	0	0	-0.1	0.1	-0.1	0	-0.1	-0.1	0	0	0
	-8										0	0	0	0	0	0	0	0	0	-0.1	-0.1	-0.1	0	0
	-9										0	0	0	0	-0.1	0	0	0	-0.1	-0.1	-0.1	-0.1	0	0
	-10										0	0	0	0	0	0	0	0	0	0	0	0	0	0

NM = not measured

T-3. Erosion Pin Data.

FIELD INVESTIGATION PROTOCOLS

SET UP

1. Determine beach area to be studied. Land and unload equipment away from the actual study area. Circle the study with stakes and red flagging to eliminate unnecessary disturbance.

2. Set gages perpendicular to study area, one in six feet of water and one in 1 foot of water. Drive in fence posts, then attach gage. Use fence post driver or sledgehammer. Set a fence post in between the two gages, 50 feet landward of the furthest gage from shore. Set buoys next to gage 1 and fence post to better time wave celerity.

3. Set 2 buoys parallel to shore, 90 feet out from shore and 100 feet apart. This will mark the outside sailing line for the boat and will be used to calculate boat velocity. ($d/t = v$) Place additional buoys to warn people of gages, fence post and ISCO sampler as needed..

4. Push 20 erosion pins in ½ way to the zero mark, place 10 pins landward and 10 pins waterward spaced 0.5 feet apart and perpendicular to the shoreline but in line with the gages.

5. Set up the ISCO intake attached to the threaded rod in approximately 1 foot of water 1 inch off the bottom, facing the shoreline and in line with the erosion pins.

6. Place the sediment traps in line with the erosion pins in 1 foot of water, flush with the bed of the river. This will sample approximately 2 inches off the bottom. Stake the traps down with bent rerod. Place one sediment trap with the long edge parallel to shore and the other with the short edge parallel to shore.

7. On shore, set up the Cam Corder to record waves at the furthest gage (gage 2 in 6 feet of water).

8. Set up Hydrolab upstream of all other activity on fence post in 1 foot of water.

9. Take three beach sediment samples from study area in line perpendicular to shore - bag, identify location, date, time and initial. Take sample 1 above wl, 2 at wl, and 3 below wl.

10. Measure advective vertical and horizontal flow velocity profiles.

11. Record gage height at Stillwater gage (can be obtained from Corps after the fact).

12. Measure Wind Speed and Magnitude.

13. Document with pictures as appropriate.

A-1. Field Data Collection Set Up.

FIELD INVESTIGATION PROTOCOL
DATA COLLECTION

Person A

1. Person A will communicate by walkie talkie to Person C all info and the ok to start each run.
2. Person A will have Person C in place to run boat upstream, guided by buoys.
3. Runs will be incremental, starting with a slow no wake and slowly building wave height. Person A will time the boat between buoys in order to calculate a velocity.
4. Person A will write down all data on the data collection sheet and make sure it is complete with all field information.

Person B

1. Start Cam Corder pointing at gage 2 at the beginning of the run, holding clip board in front of the camera just prior to run to document run # and speed.
2. Visually determine and record a starting water level and a max gage amplitude height at gage 2 (furthest) for each run.
3. Assist Person E after each run.

Person C

1. Pilot boat. For each run, the boat is to be guided, upstream, parallel to shore, along outside sailing line marked by buoys, at a constant speed. Note speed and tachometer reading.
2. The boat should be up to the predetermined speed well before the first buoy and continued on well past the gage. Do not return until to the starting position until directed by Person A.

Person D

1. Run ISCOs and measure turbidity using the HACH turbidimeter. Reverse ISCOs pumps when the boat first takes off, set to forward pumping when the boat passes gage 2 (furthest). Collect successive 1 liter volume. Measure turbidity.
2. Reset equipment for next run.

Person E

1. Set up sediment traps and recover samples for each run. Run sample through sieve to de-water, use squirt bottle to get all material from trap into sieve, bag and label - trap orientation, run #, date, time and initials.
2. Reset traps for next run.

Person F

1. Measure the time it takes for a wave to pass from gage 2 (furthest) to the fence post.
2. Set up erosion pins for each run. Measure the change in sand height on the erosion pins.
3. Reset the pins

Person G

1. Count the total number of waves passing gage 1. (closest).
2. Measure total time for all waves to pass gage 1.
3. Visually determine and record a starting water level and a max gage amplitude height at gage 1 (closest) for each run.

Person H

1. Calibrate Hydrolab in Lab prior to field investigations.
2. In the field, set up Hydrolab in one foot of water with probe 1 inch from channel bottom, upstream of all activity. Program Hydrolab to take continuous water quality measurements. Record before and after parameter measurements and note any other observations.

A-2. Data Collection Protocols.

LABORATORY PROTOCOLS

1. All Sediment Samples (including beach, and sediment trap samples) - Air dry samples in the lab. Sieve samples by hand. Record particle size distribution by weight. Plot particle size distribution by weight on cumulative frequency curves. Record total weight.

Table 1. The following screen sizes will be used to characterize particle size distribution:

Screen #	Size Opening (inches)	Particle Size
10	.0787	Gravel
35	.0197	Course Sand
60	.0098	Medium Sand
120	.0049	Fine Sand
<120	<.0049	Very Fine Sand, Silts and Clays

2. The Hydrolab will be calibrated to the manufactures specifications before and after the sampling event. No water quality samples will be analyzed at the lab.

3. Video Recordings - Will be viewed to verify field determination of maximum wave height.

A-3. Laboratory Protocols.

ST. CROIX RIVER
RECREATIONAL BOATING INVESTIGATIONS
FIELD DATA SHEETS

PERSON A ______________________________ Controlled Run Location ________________

Date _____________ Run# ______ Boat V(t) ____ ft / _____ sec V(calc) ________ mph

PERSON B _________________________ Cam Corder OK yes / no

Gage 1 Water Level Start WL __________ Max Wave WL __________

PERSON C ______________________________

Speedometer _____mph Tachometer_____X 1000 RPM Type of Boat__________________

Boat Length ______ Sitting Draft ______ Type Hull _______ Horsepower ________

PERSON D ______________________________ ISCO Turbidity _________ NTU

PERSON E _________________________________ Sediment Traps Samples OK yes / no

PERSON F ________________________________ Time Gage 1 to Post____ft / ____sec

Erosion Pins (work waterward and indicate water line)

#1_______ #2________ #3_______ #4 _______ #5_______ #6_______

#7_______ #8_______ #9_______ #10______ #11_______ #12_______

#13______ #14______ #15______ #16_____ #17______ #18______

#19______ #20______ #21______ #22______ #23______ #24______

PERSON G ___________________________ Total # of Waves _____

Total Time _________sec Gage 2 Water Level Start WL_________ Max Wave WL ________

PERSON H_________________________________ Hydrolab Continuous Turbidity__yes / no__

Before Run

pH_____ DO_____ Spec Cond _______ Turbidity _____ Temp______ Redox _______

After Run

pH_____ DO_____ Spec Cond _______ Turbidity _____ Temp______ Redox _______

A-4. Example Data Collection Sheets.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 7

THE EFFECTS OF RECREATIONAL BOATING ON SHORELINE SEDIMENT EROSION, RESUSPENSION AND DEPOSITION

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Mississippi River Hydrologist

Minnesota Department of Natural Resources
Division of Waters

February 17, 1999

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ABSTRACT

In the summer of 1995, investigations were initiated to better understand the effects of recreational boating on shoreline sediment erosion, resuspension, and deposition. Automatic samplers were programed to collect water samples in 10 minute intervals on off-peak (light boating activity) and peak (intense and sustained boating activity) days at 9 individual locations. Composite water samples were measured for turbidity. A select number of composite samples, representing a range of turbidity values, were tested for total suspended solids (TSS) and Chlorophyl *a*. While turbidity values remained relatively low throughout all sampling periods, there was a slight increase in turbidity observed on peak boating days.

Erosion pins were placed landward and waterward perpendicular to the waterline, and changes in the surface profile were measured at the end of the day. Significant changes in the beach and nearshore surface were detected, but the findings were confounded by constant reworking of the beach and nearshore sediments by waves and changing water levels throughout the day.

In the summer of 1998, additional investigations of off-peak and peak boating days included the measurement of maximum wave heights, number and type of boats, shoreline sediment mobilization (erosion and resuspension), and deposition. The study results confirmed the 0.4 foot sediment mobilization threshold identified in the controlled run studies. The more boat waves 0.4 feet and higher in a 30 minute monitoring period, the greater the amount of sediment mobilized and redeposited in the sediment traps. Likewise, the larger the maximum wave height in a 30 minute monitoring period, the greater the amount of sediment mobilized and redeposited. Of all the boat types recorded, runabouts and cruisers had the highest correlation to the measured maximum wave heights, amount of sediment mobilized, and number of waves greater than the sediment mobilization threshold (0.4 feet).

INTRODUCTION AND PURPOSE OF STUDY

Since the late 1980s there has been a growing concern by St. Croix River users and managers that recreational boating activity may be having a deleterious effect on island and channel shorelines. Following a public meeting in March of 1994, the natural resource agencies responsible for management of the St. Croix River agreed to design studies and collect field data to measure the possible negative impacts recreational boating may have on islands and channel shorelines.

The Illinois State Water Survey (Bhowmik *et al.* 1991) concluded that recreational boats on the Illinois and Mississippi rivers are capable of generating waves of sufficient magnitude to necessitate an evaluation of their potential to contribute to bank erosion or shoreline instability.

In a study conducted by the Minnesota Department of Natural Resources (Johnson, 1994), waves generated by recreational boats were identified as the largest contributing influence responsible for the accelerated Mississippi River shoreline erosion near Red Wing. Elevated turbidity measurements on the Upper Mississippi River were associated with the erosion and resuspension of sediment during peak recreational boating times. These elevated turbidity values were persistent and laterally extensive.

Researchers on the Gordon River (Nanson *et al.* 1994) found, that of the numerous wave characteristics that can be measured or calculated, maximum wave height was the easiest to measure and correlated well with increased shoreline erosion. Through the use of erosion pins, researchers on the Gordon River documented bank erosion rates.

METHODS

1995 Investigations

Automatic (ISCO) water samplers were deployed on three peak and three off-peak boating days at nine locations within the study area (figure 1 and table 1). Main channel and backwater locations were sampled on each day. The intake tube was positioned 0.5 feet from the sediment/water interface on a threaded rod anchored in the bottom substrate. The water samplers were programed to collect a water sample every 10 minutes from 6 AM to 8 PM. Samples were combined to make 30 minute composite samples for turbidity analysis. Samples were analyzed back at the laboratory using a HACH turbidimeter. Selected composite samples were tested for total suspended solids (TSS) and Chlorophyl *a* values at the Minnesota Department of Agriculture laboratory.

Erosion pins were pushed into the shoreline sediment at 0.5 foot intervals both landward and waterward, perpendicular to the waterline, at the start of the monitoring day. At the end of the day (8:00 PM) the total amount of sand eroded or deposited at each pin was measured for each site.

1998 Investigations

Maximum wave heights generated by recreational boats were measured at three sites spanning a full range of recreational boating activity levels. The amount of sediment mobilized and redeposited in sediment traps, the number and type of recreational boats, and the net amount of change of the nearshore and beach surface profile were measured during each 30 minute monitoring period.

A gage was installed offshore in 4 feet of water to measure maximum wave heights uninfluenced by wave/river bottom interactions. Maximum wave heights equal to or greater than 0.4 feet, as well as the highest peak, were recorded for each 30 minute monitoring period. The amount of sediment mobilized was quantified using sediment traps and erosion pins (figures 2 and 3). Sediment traps were placed in 1 foot of water and samples were retrieved every 30 minutes for drying and weighing back in the laboratory. Erosion pins were placed at 0.5 foot

increments, 10 landward and 10 waterward, all perpendicular to the waterline. For every 30 minute monitoring period, the amount of erosion and deposition was noted at each erosion pin, and the pins were reset. Boats were counted and classified using Minnesota Wisconsin Boundary Area Commission's boating survey categories.

RESULTS AND DISCUSSION

Turbidity

In 1995, ISCO composite water sample turbidity values were elevated slightly on peak boating days. At sites 11A, 11B, 12A, and 12B, turbidity values during off-peak (Wednesday 8/2/95) and peak (Saturday 8/5/95) boating days all remained at or below 15 nephelometric turbidity units (NTUs) (figures 4 and 5). At sites 2A and 2B, a very slight rise in turbidity was noted on Saturday 8/19/95, but values remained under 15 NTUs (figure 6). At site 4, turbidity ranged from between 7 and 12 NTUs on the mornings of Tuesday (8/15/95) and Saturday (8/19/95) but slowly rose on both dates to values between 20 and 32 NTUs in the afternoon (figure 7). It is likely polluted runoff following heavy rains in the watershed raised the turbidity values on both dates. At site 7, Saturday (9/16/95) turbidity values ran fairly consistent between 8 and 13 NTUs except for on Tuesday (9/12/95) when turbidity values dropped to around 5 NTUs after 9 AM (figure 8). At Site 10, turbidity measurements generally ran below 15 NTUs with occasional spikes between 20 and 33 NTUs on both Tuesday (9/12/95) and Saturday (9/16/95) (figure 9).

In general, the turbidity changes were relatively unremarkable between peak and off-peak days and between early morning and later afternoon values. The slight increase in turbidity measured on peak boating days did not significantly degrade water clarity and is unlikely to have a substantial impact on light penetration to aquatic plants.

Turbidity measurements are used as a surrogate measurement for TSS and/or the amount of algae present as measured by Chlorophyl *a*. Regression analysis of TSS, Chlorophyl *a* and measured turbidity values resulted in very low R^2 values. The TSS and Chlorophyl *a* laboratory results did

not explain the variability among turbidity values. In other words, the laboratory results suggest no significant difference in turbidity among samples (table 2, figures 10 and 11) due to TSS or Chlorophyll *a* concentration differences.

An analysis of the sediment particle size distribution of the sediments in the study area indicates that less than 1 percent silt and clay size particles by weight are available for resuspension (figure 12). The lack of fine grain sediments explains the relatively small turbidity changes and low TSS values in the study area. Because of their relatively large size, mobilized sand size sediment particles remain low in the water column near the river bottom and appear to be redeposited seconds after wave dissipation. For the ISCO samplers to catch the sand particles in the resuspension event, water samples would essentially need to be taken at the same time waves were impinging on the shoreline and waves would have to be of great enough magnitude to resuspend the sand size particles at least 0.5 feet into the water column.

<u>Erosion and Deposition</u>

The 1995 erosion pin data suggests that sediment was eroded and redeposited on the beach and nearshore, but that the amount, location and timing was highly variable. Erosion ranged from 0 to 1.8 inches, and deposition ranged from 0 to 1.9 inches per pin, as measured at the end of the day. During the course of a day of monitoring, it was observed that a cycle of sediment deposition, erosion, and redeposition would occur if recreational boating activity was high and at a sustained level. These observations suggest that the erosion pin data collection interval may have been mismatched to the wave erosion and redeposition dynamics. A drop in water levels over the day further confounded the findings.

In 1998, erosion pins were used to measure changes in beach and nearshore surfaces in 30 minute monitoring periods spanning varying levels of recreational boating activity. The erosion pins were then immediately reset for the next 30 minute interval. In general, most of the sediment surface changes occurred waterward of the waterline. Absolute total change (erosion plus deposition) ranged from 0 to 2.4 inches per 30 minute monitoring period (table 3). There was a poor correlation between absolute total change as measured by the erosion pins and the amount

of sediment redeposited in the sediment traps. The results suggest that erosion pin and sediment trap techniques measure erosional and depositional events at different spatial and temporal scales, and the results do not readily lend themselves to simple comparisons.

Sediment Mobilization and Redeposition

The sediment mobilization threshold discovered during the controlled run recreational boat studies was verified by the recreational boating field studies. Monitoring periods with no maximum wave heights greater than 0.4 feet (12/36 monitoring periods) resulted in very little sediment redeposition (0 to 13 grams) in the sediment traps. Sampling intervals with maximum wave heights greater than 0.4 feet showed a marked increase in sediment redeposition (up to 894 grams) in the sediment traps (figure 13). In general, measured maximum wave heights were less than 1.0 feet (table 3).

In addition to the maximum wave height measurements, the number of recreational boat waves greater than 0.4 feet were recorded for each 30 minute monitoring period (table 3). The number of waves greater than 0.4 feet ranged from 0 to 95 waves per 30 minute monitoring period. In general, the more waves greater than 0.4 feet in height, the more sediment mobilized and redeposited in the sediment traps (figure 14).

Further analysis also suggests that when wave height frequency exceeds 50 waves greater than 0.4 feet in height per 30 minute monitoring period, sediment redeposition may be reduced because of continuous sediment resuspension. This continued resuspension may facilitate material being moved farther away from shore by advective currents. A regression analysis that excluded the 3 sediment trap value outliers (>50 waves/30 min.) was completed and regression line plotted (figure 14). The regression line in figure 14 fits the sediment trap data very well with an R^2 value of 0.95.

The number and types of boats recorded for each of the 36 sampling periods were tabulated and summarized (table 3). A statistical correlation matrix using Pearson's *r* values was developed to measure the relative strength of correlation among the types of boats, maximum wave heights,

sediment mobilized and number of waves greater than 0.4 feet (table 4). Correlation *r* values can range from -1 to 1. An *r* value of zero indicate no correlation while r values of 1 or -1 indicate a perfect positive or inverse relationship, respectively. The correlation matrix results show that of the 7 boat categories, runabouts and cruisers generally had the strongest correlation with maximum wave heights, sediment mobilized and the number of waves greater than 0.4 feet. Of all the vessels counted, 46 percent were classified as runabouts and 15 percent cruisers.

Jet skis represented 17 percent of the total boats and were strongly correlated with maximum wave heights. The percentage of jet skis and their strong correlation to maximum wave heights were attributed to jet skiers following runabouts and cruisers in their desire to jump large waves as a way to enhance their recreational experience.

CONCLUSIONS

Due to the lack of fine grain particles in the shoreline sediments, recreational boat waves do not appear to significantly raise or sustain higher turbidity values in the St. Croix River nearshore zone. While the erosion pin results clearly illustrate erosional and depositional changes in beach and nearshore surfaces, the sequence of events leading to the observed changes were obscured by the continuous reworking of the sediment by recreational boat waves and changing water levels.

The sediment trap results confirm the existence of a sediment mobilization threshold of 0.4 feet first observed in the controlled runs. In addition, the sediment trap data suggests that the more wave heights above the sediment mobilization threshold, the more nearshore and beach sediment mobilized and redeposited.

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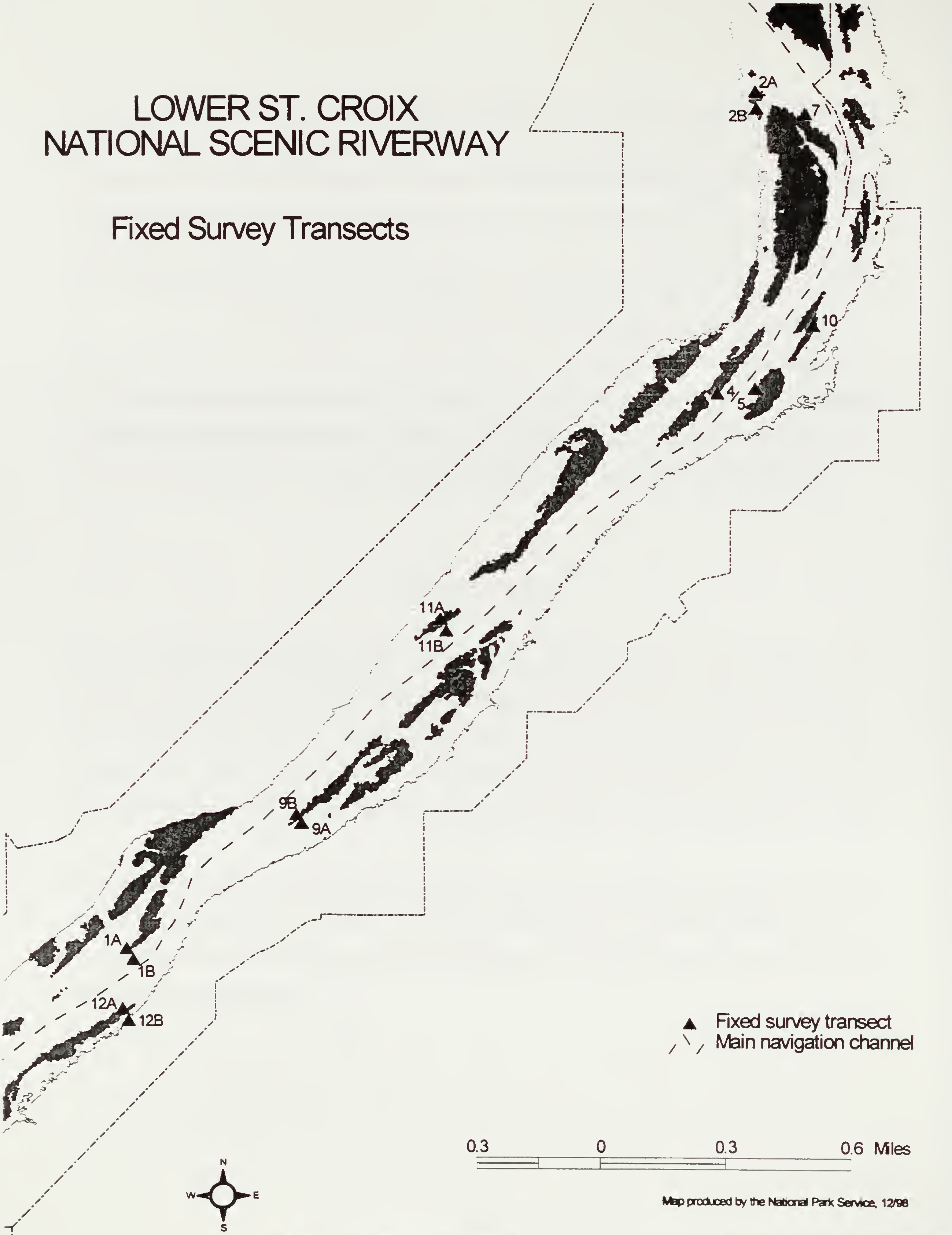

Figure 1. Study Area Location Map and Sampling/Monitoring Locations.

PROTOTYPE FOR SEDIMENT TRAP

(not to scale)

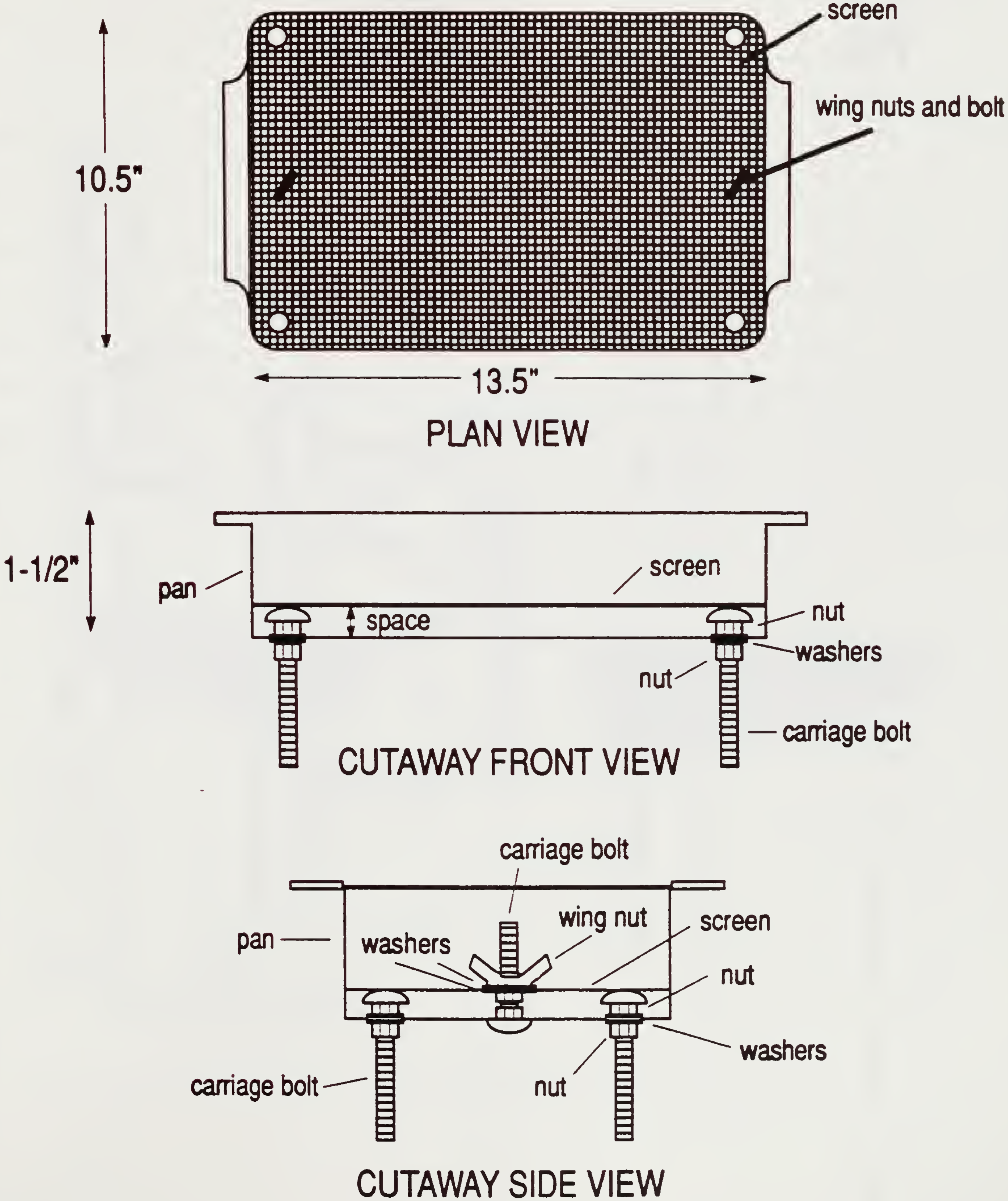

Figure 2. Sediment Trap Diagram.

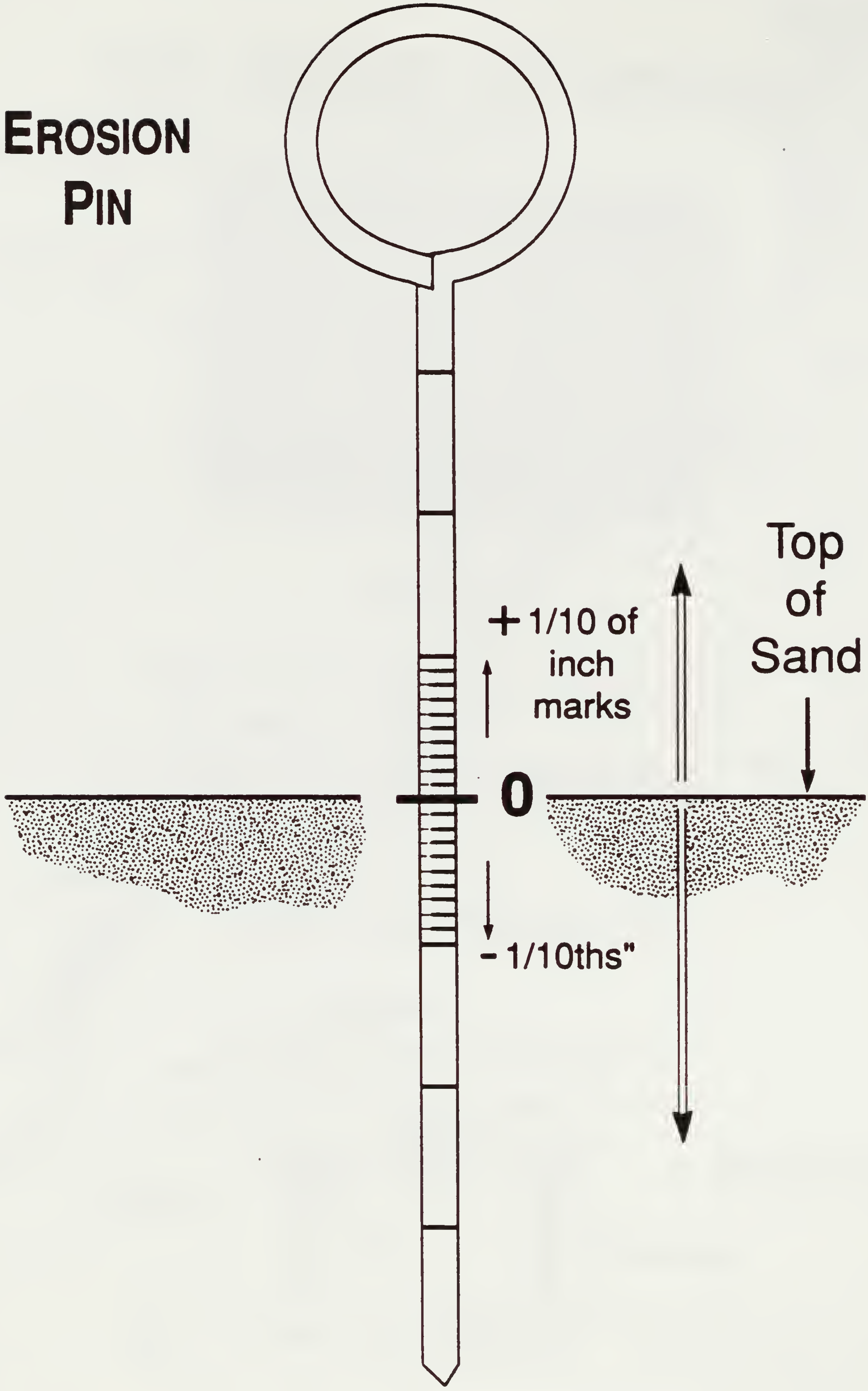

Figure 3. Erosion Pin Diagram

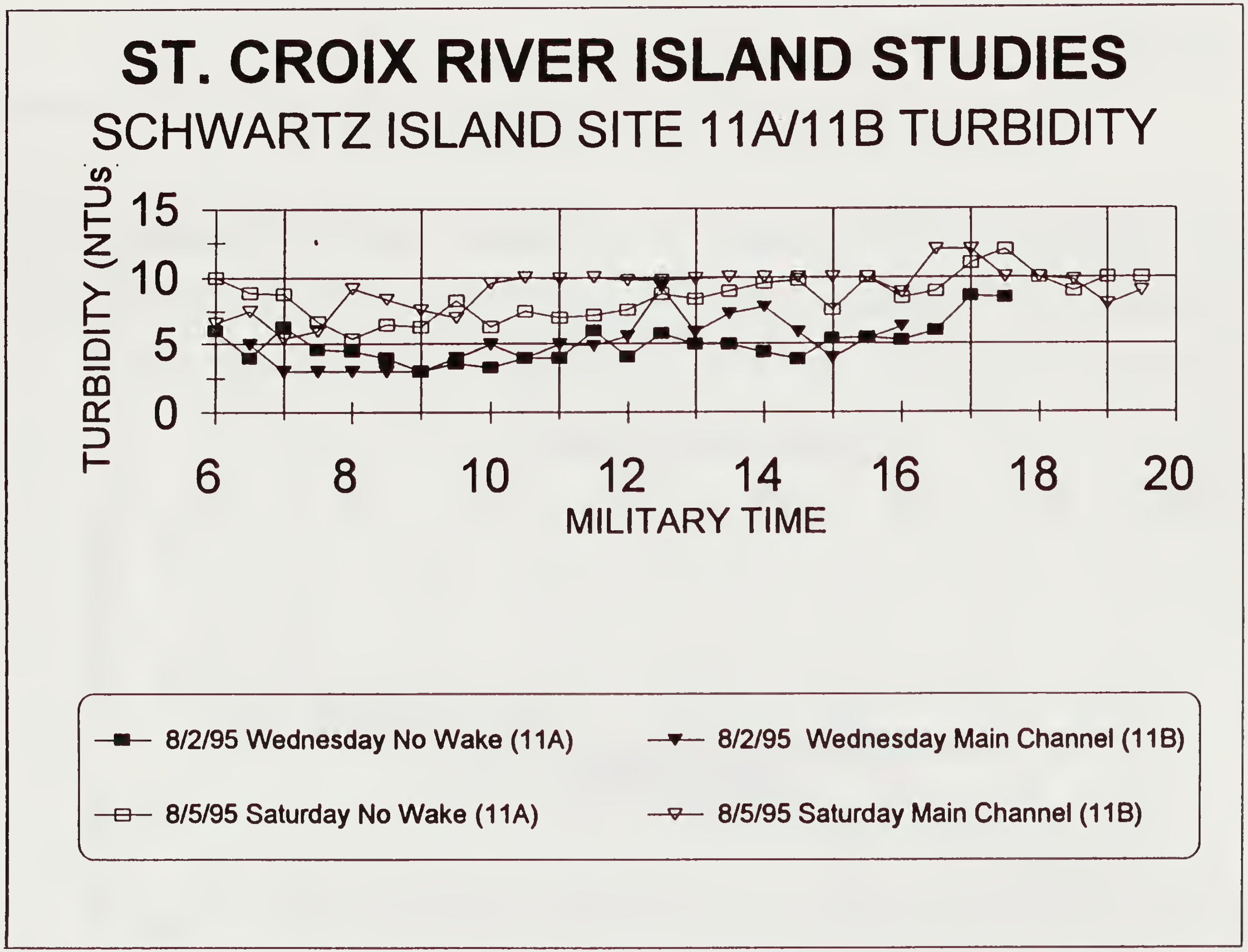

FIGURE 4. SCHWARTZ ISLAND SITE 11A AND 11B TURBIDITY.

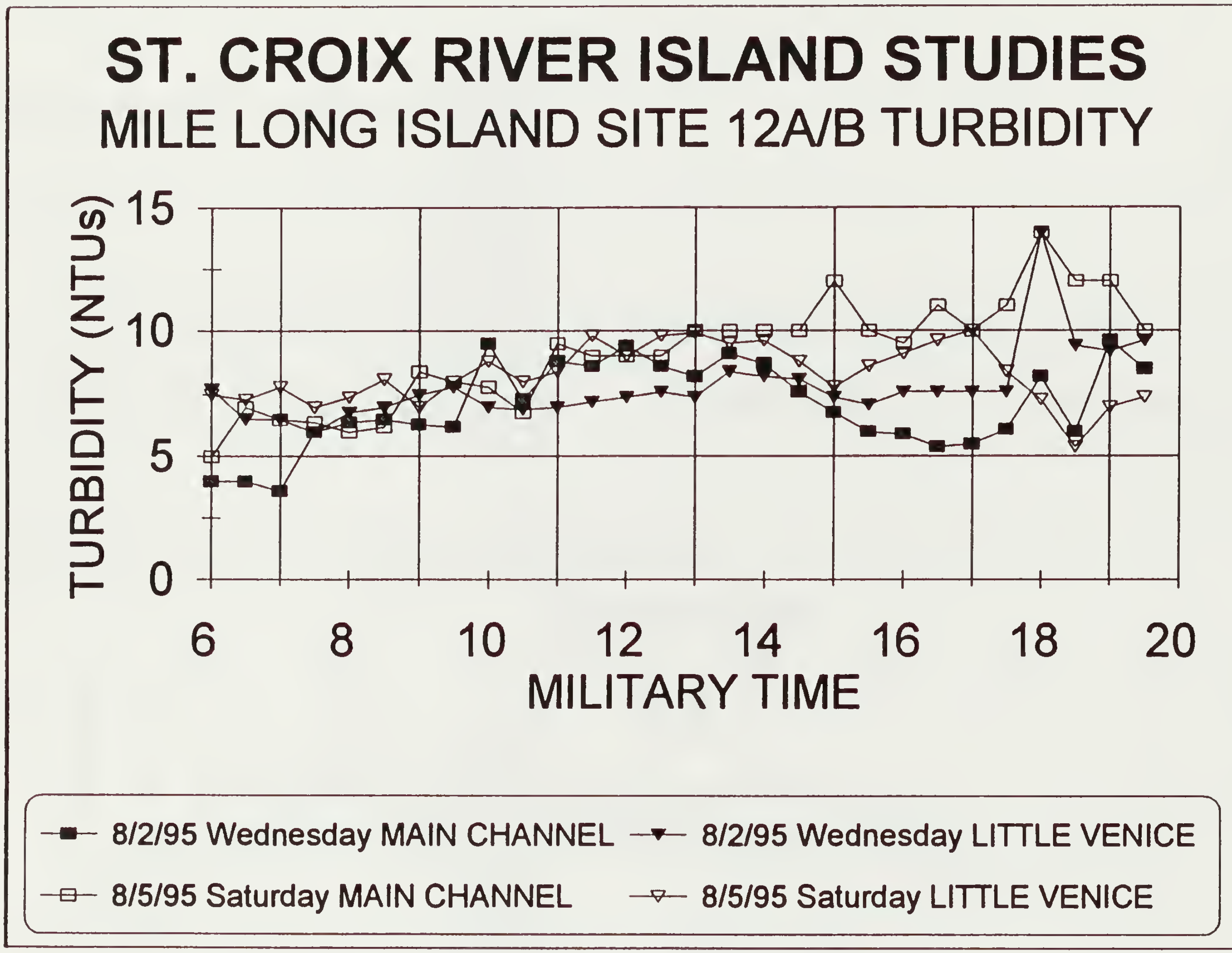

FIGURE 5. MILE LONG ISLAND SITE 12A AND 12B TURBIDITY (12A = MAIN CHANNEL, 12B = LITTLE VENICE).

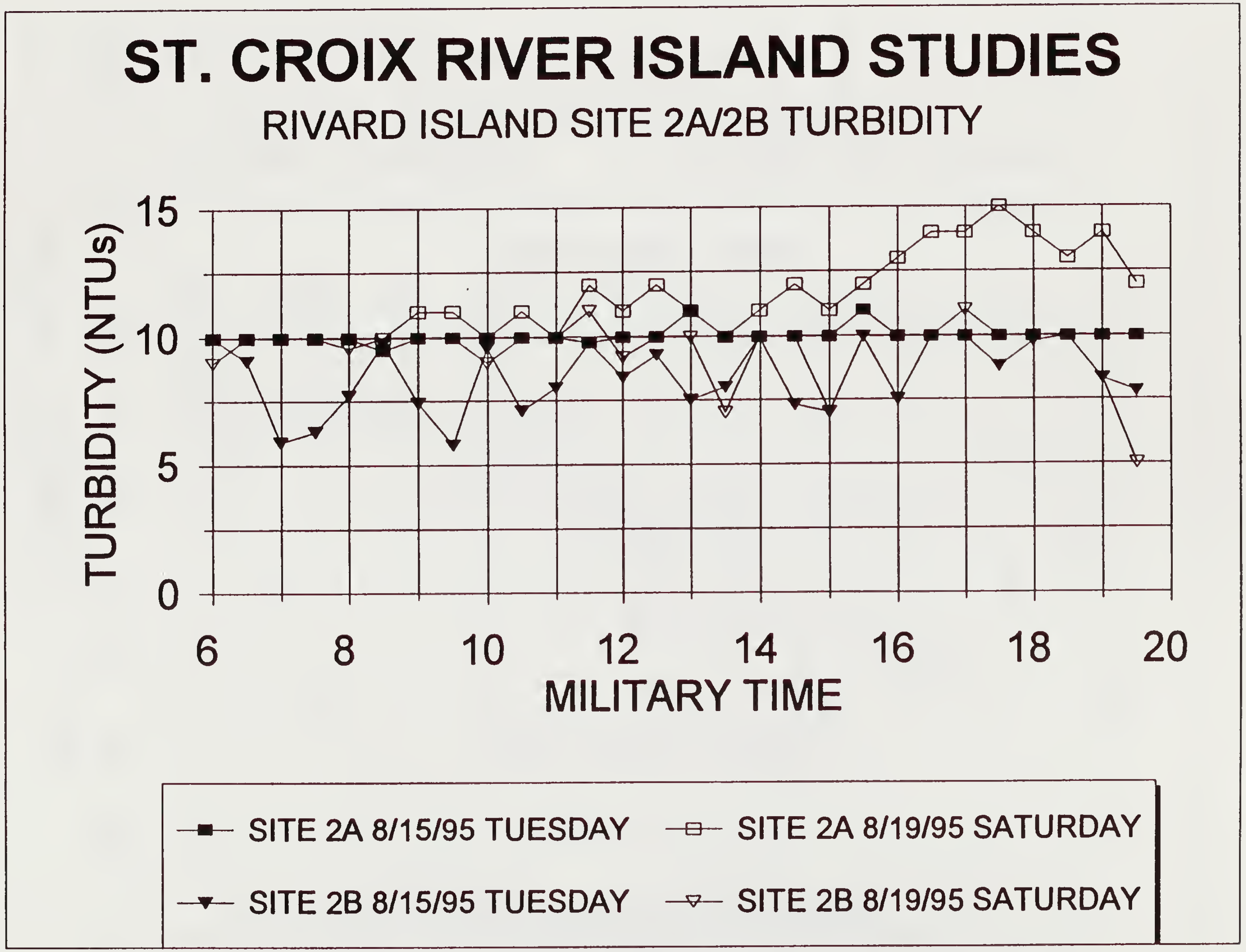

FIGURE 6. RIVARD ISLAND SITE 2A/2B TURBIDITY.

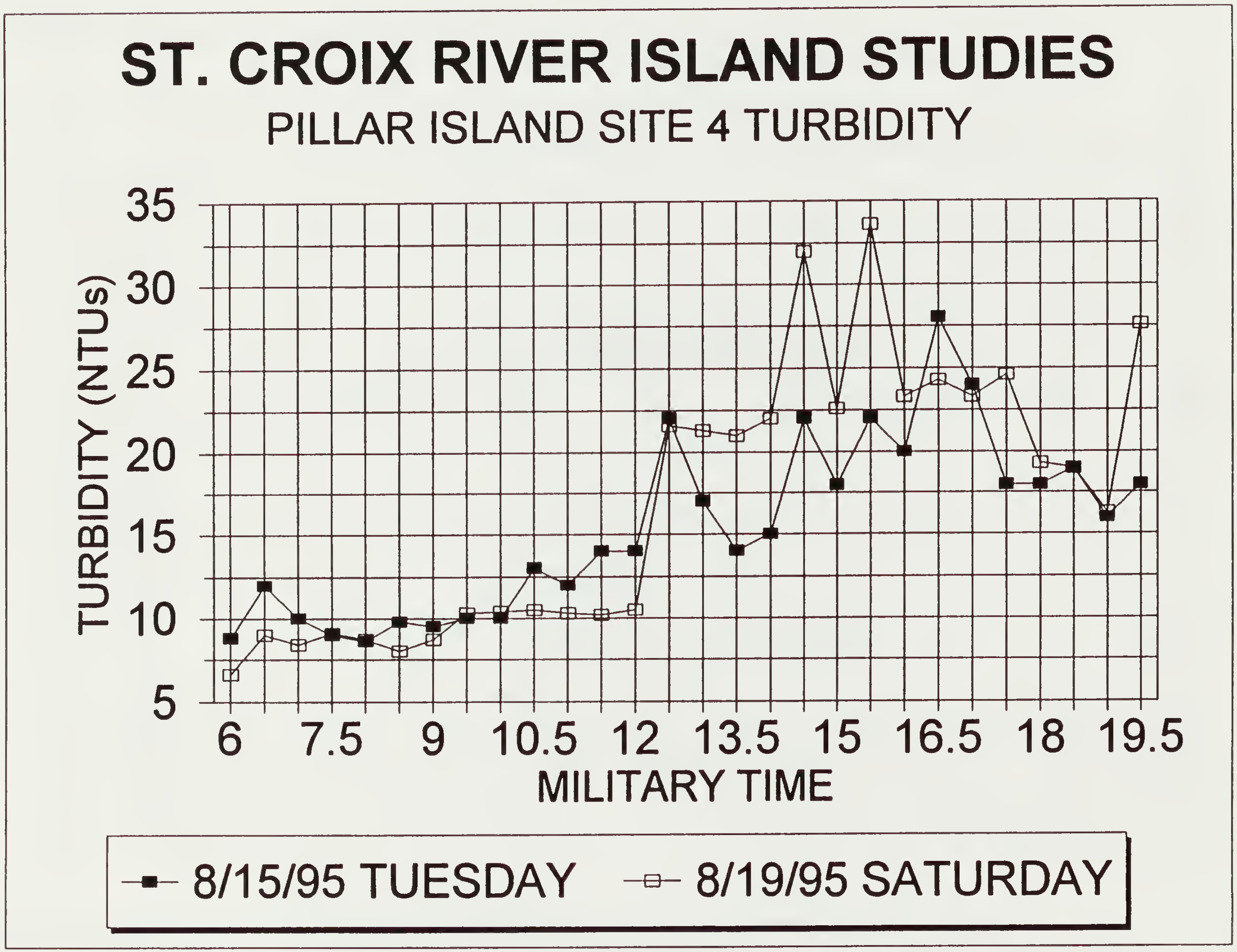

FIGURE 7. PILLAR (PIER) ISLAND SITE 4 TURBIDITY.

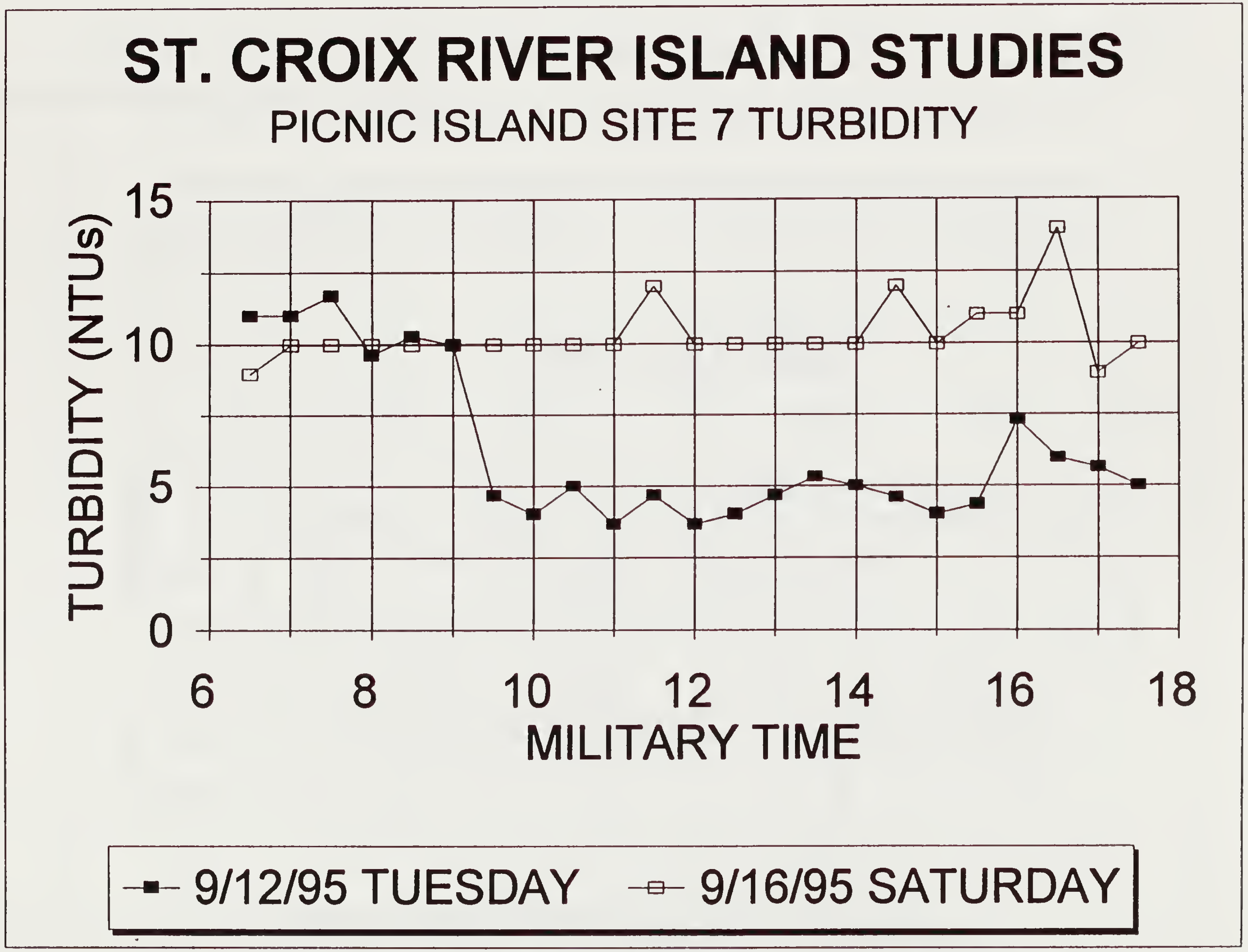

FIGURE 8. PICNIC ISLAND SITE 7 TURBIDITY.

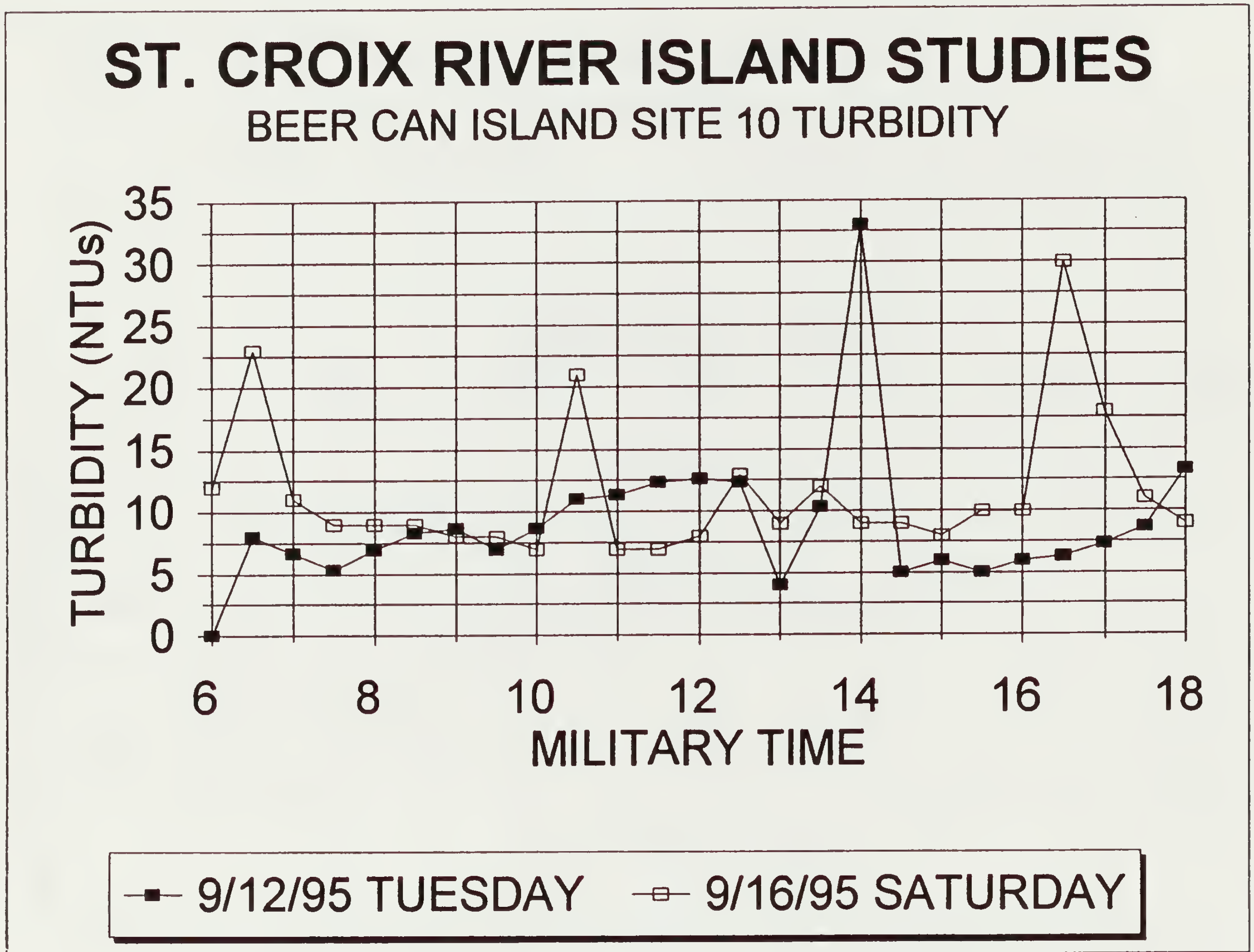

FIGURE 9. BEER CAN ISLAND SITE 10 TURBIDITY.

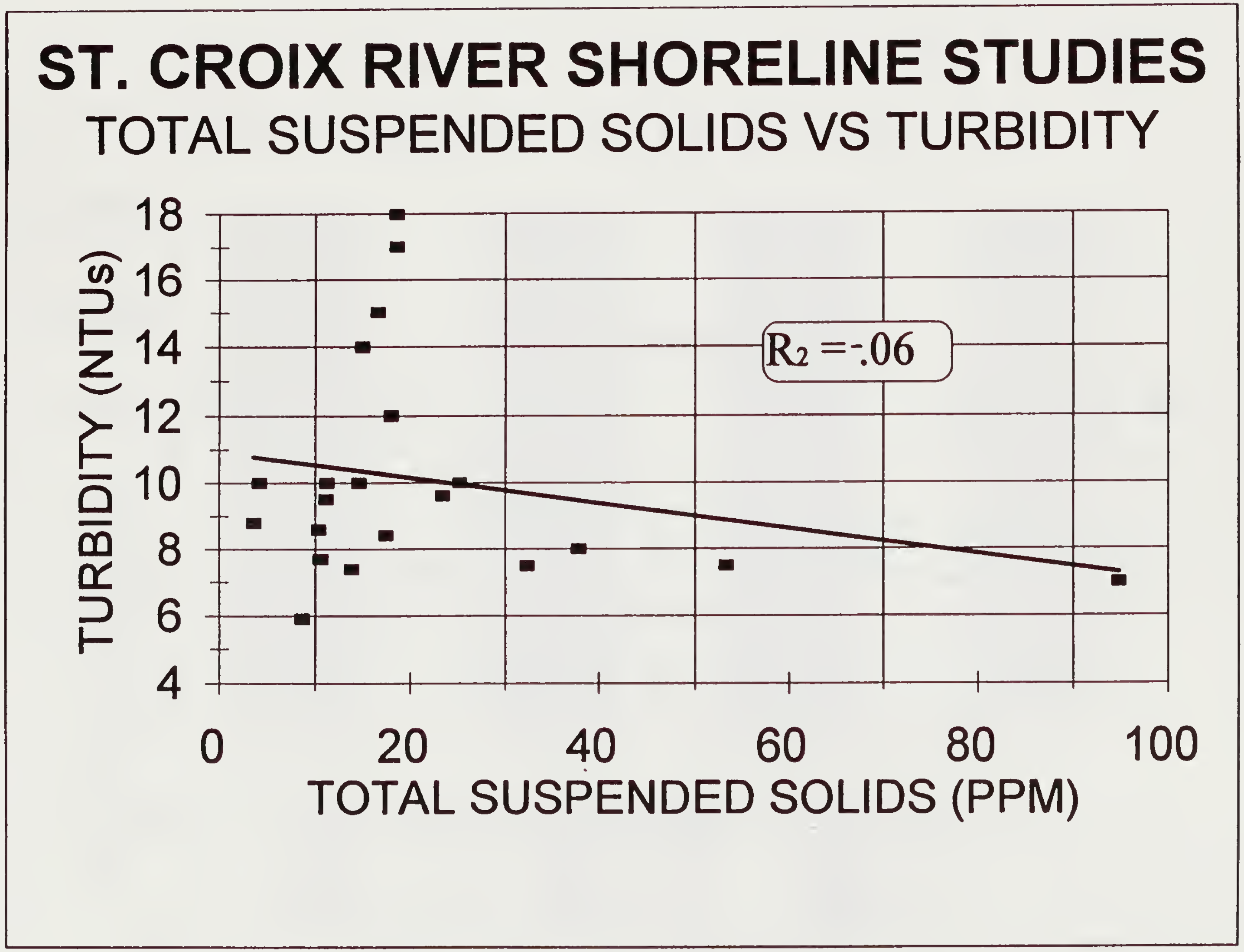

FIGURE 10. TOTAL SUSPENDED SOLIDS VS TURBIDITY VALUES.

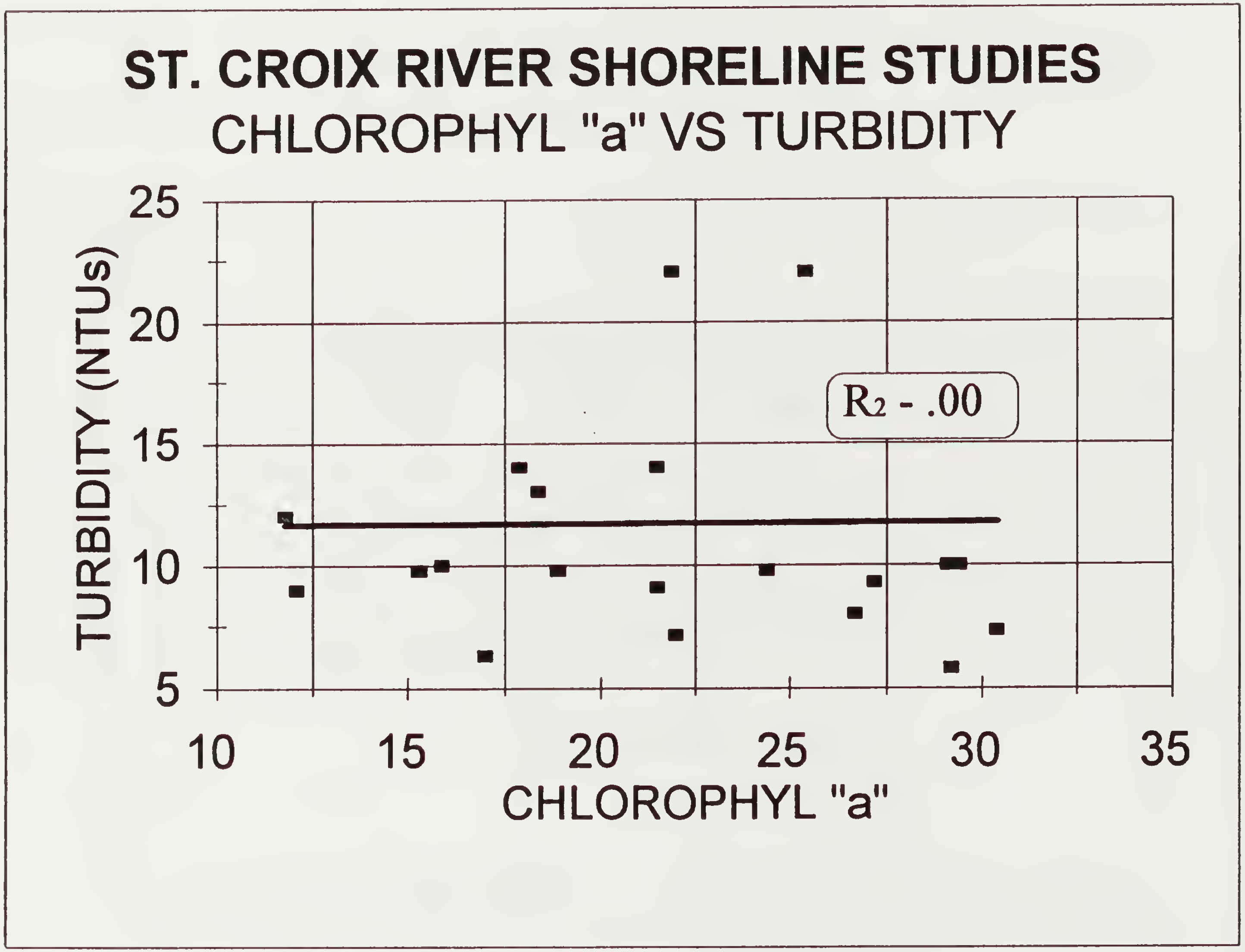

FIGURE 11. CHLOROPHYL "a" VERSUS TURBIDITY VALUES.

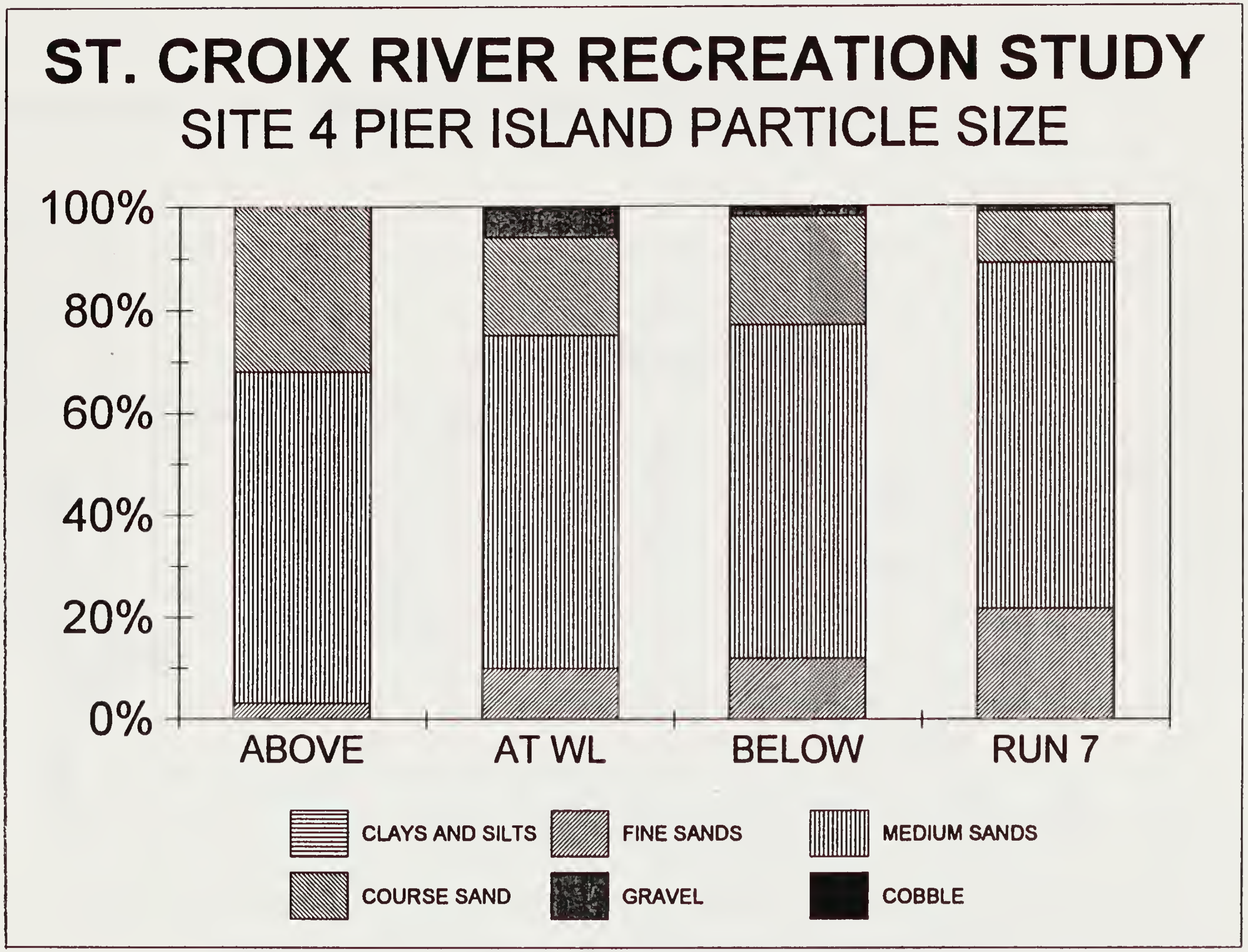

FIGURE 12. PIER (PILLAR) ISLAND SITE 4 PARTICLE SIZE DISTRIBUTION.

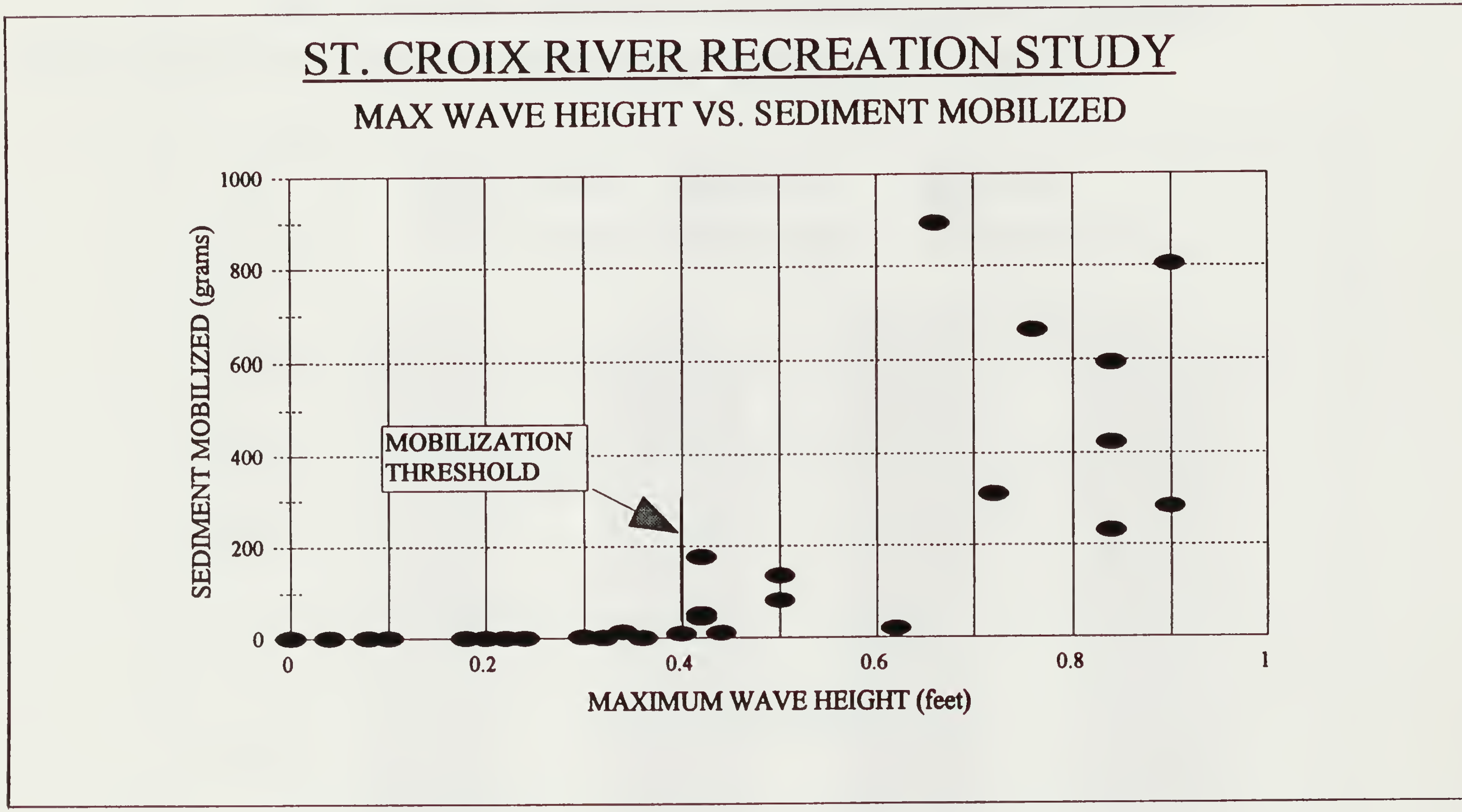

FIGURE 13. MAXIMUM WAVE HEIGHT vs SEDIMENT MOBILIZED.

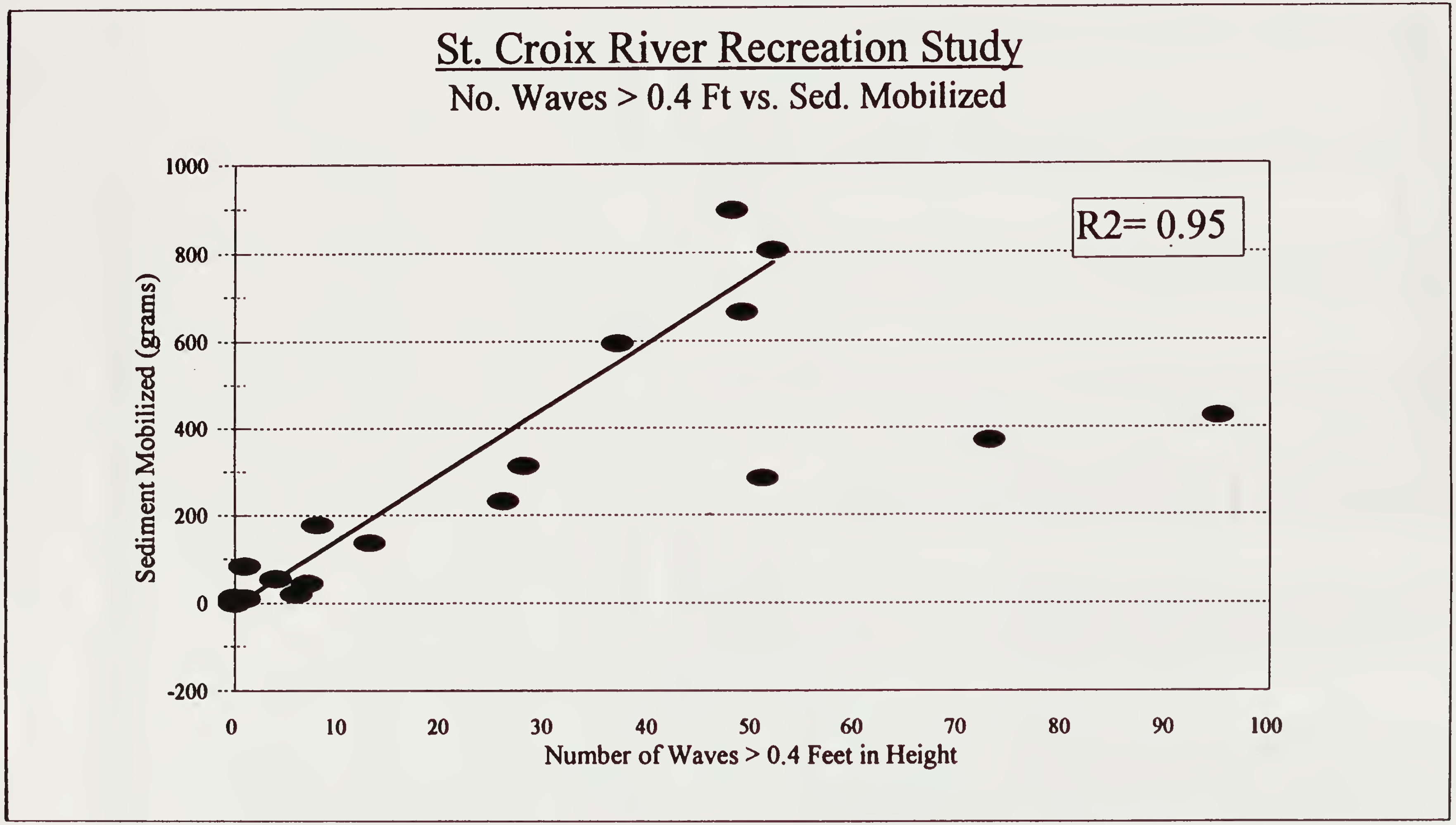

FIGURE 14. NUMBER OF WAVES >0.4 FEET VS SEDIMENT MOBILIZED.

NORMAL BOATING ACTIVITY (UNCONTROLLED) 1995

LOCATION	DATE	DAY	
SITE 2A RIVARD ISLAND	8/15/95	TUESDAY	NBYT
	8/19/95	SATURDAY	NBYT
SITE 2B RIVARD ISLAND	8/15/95	TUESDAY	NBYT
	8/19/95	SATURDAY	NBYT
SITE 4 PIER ISLAND	8/15/95	TUESDAY	YBYT
	8/19/95	SATURDAY	YBYT
SITE 7 PICNIC ISLAND	9/12/95	TUESDAY	YBYT
	9/16/95	SATURDAY	YBYT
SITE 10 BEER CAN ISLAND	9/12/95	TUESDAY	NBYT
	9/16/95	SATURDAY	NBYT
SITE 11A SWARTZ ISLAND	8/2/95	WEDNESDAY	NBYT
	8/5/95	SATURDAY	NBYT
SITE 11B SWARTZ ISLAND	8/2/95	WEDNESDAY	YBNT
	8/5/95	SATURDAY	YBNT
SITE 12A MILE LONG ISLAND	8/2/95	WEDNESDAY	YBYT
	8/5/95	SATURDAY	YBYT
SITE 12B MILE LONG ISLAND	8/2/95	WEDNESDAY	NBNT
	8/5/95	SATURDAY	NBNT

KEY

NB = NO BOAT WAVE IMPACTS
YB = YES BOAT WAVE IMPACTS
NT = NO FOOT TRAFFIC TRAMPLING
YT = YES FOOT TRAFFIC TRAMPLING

Table 1. 1995 Recreational Boating Turbidity Sampling Sites.

TURBIDITY/TOTAL SUSPENDED SOLIDS/CHLOROPHYL "A"

SAMPLE	TSS	TURBIDITY	REG LN	CHL "A"	TURBIDITY	REG LN
1.00	3.60	8.80	10.79	11.80	12.00	11.65
2.00	4.20	10.00	10.77	12.10	9.00	11.65
3.00	10.40	8.60	10.53	15.30	9.80	11.67
4.00	11.20	9.50	10.50	15.90	10.00	11.67
5.00	14.60	10.00	10.37	18.40	13.00	11.69
6.00	18.00	12.00	10.24	17.90	14.00	11.68
7.00	15.00	14.00	10.35	21.90	22.00	11.71
8.00	18.60	17.00	10.22	21.50	14.00	11.71
9.00	16.60	15.00	10.29	25.40	22.00	11.73
10.00	18.60	18.00	10.22	25.40	22.00	11.73
11.00	11.30	10.00	10.50	21.50	9.10	11.71
12.00	8.70	5.90	10.60	17.00	6.30	11.68
13.00	10.60	7.70	10.52	18.90	9.80	11.69
14.00	13.90	7.40	10.40	29.20	5.80	11.75
15.00	23.50	9.60	10.03	22.00	7.10	11.71
16.00	37.90	8.00	9.48	24.40	9.80	11.72
17.00	17.50	8.40	10.26	27.20	9.30	11.74
18.00	32.40	7.50	9.69	26.70	8.00	11.74
19.00	25.30	10.00	9.96	30.40	7.30	11.76
20.00	94.80	7.00	7.29	29.10	10.00	11.75
21.00	53.40	7.50	8.88	29.40	10.00	11.75

Regression Output:			Regression Output:		
Constant		10.93	Constant		11.58
Std Err of Y Est		3.30	Std Err of Y Est		5.06
R Squared		0.06	R Squared		0.00
No. of Observations		21.00	No. of Observations		21.00
Degrees of Freedom		19.00	Degrees of Freedom		19.00
X Coefficient(s)	-0.04		X Coefficient(s)	-0.01	
Std Err of Coef.	0.04		Std Err of Coef.	0.20	

TABLE 2. 1995 TURBIDITY, TOTAL SUSPENDED SOLIDS/CHLOROPHYL "a" VALUES.

St. Croix River Recreational Boating Studies - Normal Boating Activities

	Time	Max. Wave Height (ft)	Sediment (g)	# Waves>0.4	canoe	sailboat	fishing	runabout	cruiser	pontoon	house	jetskis	total	absolute change pin totals
Site 12A	9:30 - 10.00	0.62	20	8	0	0	4	5	1	2	0	12	24	12
Mile Long	10:00 - 10:30	0.42	44	7	0	0	1	7	1	0	0	3	12	24
7/19/98	10:30 - 11:00	0.42	177	8	0	0	5	11	2	0	1	0	19	24
Sunday	11:00 - 11:30	0.42	54	4	0	0	5	11	2	0	1	0	19	13
	11:30 - 12:00	0.72	312	28	0	0	2	23	1	2	0	12	40	14
WATER LEVEL = 876.75	12:00 - 12:30	0.84	594	37	0	0	2	30	2	0	5	16	55	20
	12:30 - 1:00	0.5	136	13	0	0	2	19	3	1	2	10	37	18
	1:00 - 1:30	0.9	283	51	0	0	2	22	5	3	4	10	46	18
	1:30 - 2:00	0.84	425	95	0	0	7	21	14	2	4	9	57	21
	2:00 - 2:30	1.5	370	73	0	0	8	29	12	1	1	16	67	22
	2:30 - 3:00	0.84	231	26	0	0	5	15	8	4	2	8	40	10
	3:00 - 3:30	0.9	804	52	0	0	9	32	21	8	1	9	80	11
	3:30 - 4:00	0.76	663	49	0	0	7	34	13	7	1	9	71	10
	4:00 - 4:30	0.66	894	48	0	0	3	34	10	3	4	7	81	11
Picnic Island	11:00 - 11:30	0.1	0.03	0	0	0	1	0	0	0	0	0	1	11
Site 7	11:30 - 12:00	0.34	13.02	0	0	0	1	0	1	1	0	0	3	23
6/10/98	12:00 - 12:30	0.22	0.58	0	0	0	2	0	0	0	0	0	2	1
Wednesday	12:30 - 1:00	0.2	0	0	0	0	1	0	0	0	0	0	1	0
	1:00 - 1:30	0.1	0.02	0	0	0	1	0	0	0	0	0	1	2
WATER LEVEL = 676.00	1:30 - 2.00	0.08	0.08	0	0	0	1	0	0	0	0	0	1	1
	2:00 - 2:30	0.04	0	0	0	0	2	0	0	0	0	0	2	2
	2:30 - 3:00	0.04	0	0	0	0	3	0	0	0	0	0	3	0
	3:00 - 3:30	0.18	0.18	0	0	0	2	2	0	1	0	0	5	0
	3:30 - 4:00	0	0	0	0	0	0	0	0	0	0	0	0	3
Pillar Island	10:30 - 11:00	0	0	0	0	0	0	0	0	0	0	0	0	0
Site 4	11:00 - 11:30	0.36	0.35	0	0	0	1	3	0	0	0	1	5	7
8/14/98	11:30 - 12:00	0.2	0.37	0	0	0	1	2	0	1	0	1	5	20
Friday	12:00 - 12:30	0.32	1.13	0	0	0	0	2	0	0	0	0	2	18
	12:30 - 1:00	0.24	0	0	0	0	2	2	0	1	0	0	5	13
WATER LEVEL = 675.15	1:00 - 1:30	0.22	0	0	0	0	2	1	1	0	0	0	4	2
	1:30 - 2:00	0.44	11.45	1	0	0	1	7	0	0	0	0	8	14
	2:00 - 2:30	0.5	83.06	1	1	0	0	2	1	0	0	0	4	18
	2:30 - 3:00	0.32	0.4	0	0	0	2	1	1	0	0	0	4	8
	3:00 - 3:30	0	0.44	0	0	0	1	0	1	0	0	0	2	3
	3:30 - 4:00	0.4	9.63	1	0	0	2	2	1	1	0	1	7	13
	4:00 -4:30	0.3	3.3	0	0	0	0	5	1	0	0	0	6	12
				total boats	1	0	88	322	102	38	26	122	699	
				percent	0	0	13	46	15	5	4	17	100	

TABLE 3. 1998 RECREATIONAL BOATING MEASURES.

St. Croix River Shoreline Studies
Correlation Matrix for Recreational Boating Measures

	max. wave height (ft)	sediment (g)	# waves>0.4
canoe	0.05	-0.03	-0.09
fishing	0.70	0.65	0.74
runabout	0.84	0.94	0.85
cruiser	0.73	0.84	0.86
pontoon	0.56	0.74	0.61
house	0.60	0.71	0.73
jetskis	0.85	0.70	0.78

TABLE 4. 1998 CORRELATION MATRIX USING PEARSON'S "r" VALUES.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES
DATA SHEET FOR UNCONTROLLED BOATING ACTIVITY

DATE______________ LOCATION____

DAY______________ PEAK / NON-PEAK OBSERVERS______________________________

<--NUMBER OF EACH BOAT TYPE ---->

TIME	NUMBER OF WAVES > 0.4 FEET IN 30 MIN	MAX WAVE HEIGHT IN 30 MIN	TRAP Y/N	PINS Y/N	CANOE	SAILBOAT	FISHING	RUNABOUT	CRUISER	PONTOON	HOUSEBOAT
9:00 - 9:30											
9:30 - 10:00											
10:00 - 10:30											
10:30 - 11:00											
11:00 - 11:30											
11:30 - 12:00											
12:00 - 12:30											
12:30 - 1:00											
1:00 - 1:30											
1:30 - 2:00											
2:00 - 2:30											
2:30 - 3:00											
3:00 - 3:30											
3:30 - 4:00											
4:00 - 4:30											
4:30 - 5:00											
TOTALS											

Appendix 1. Data Sheet for Recreational Boating Activity.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES
DATA SHEET FOR UNCONTROLLED BOATING ACTIVITY
EROSION PINS

TIME	10	9	8	7	6	5	4	3	2	1	0	1	2	3	4	5	6	7	8	9	10
	L	A	N	D							W L						W	A	T	E	R
9:00 - 9:30																					
9:30 - 10:00																					
10:00 - 10:30																					
10:30 - 11:00																					
11:00 - 11:30																					
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3:00 - 3:30																					
3:30 - 4:00																					
4:00 - 4:30																					
4:30 - 5:00																					
TOTALS																					

Appendix 2. Data Sheet for Recreational Boating Erosion Pin Data.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 8

THE EFFECTS OF WIND GENERATED WAVES ON SHORELINE SEDIMENT MOBILIZATION

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Mississippi River Hydrologist

Minnesota Department of Natural Resources
Division of Waters

February 17, 1999

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ABSTRACT

Wind-generated waves, wind speed, wind direction, and amount of sediment mobilized were measured at 40 stratified, randomly selected (SRS) locations. All wind-generated wave heights were less than the 0.4-foot mobilization threshold identified in the controlled run studies. Only very small amounts of sediment were mobilized at locations with measurable wind waves. An analysis of historic wind data showed that on the monitoring day, winds were greater than average and from a direction for the largest possible wind fetches. An empirical equation suggested that wind speeds of the magnitude necessary to generate 0.4-foot wind waves rarely occur in the study reach.

INTRODUCTION AND PURPOSE

Shoreline erosion is a growing concern for users and managers of the St. Croix River. There are many potential contributing influences to shoreline erosion including advective flow velocity, boat-generated waves, foot traffic trampling and wind-generated waves. Gatto and Doe (1987) and Mason *et al.* (1983) articulated the difficulty in sorting out contributing influences responsible for shoreline erosion. The wind-wave study was designed to document wind-generated wave heights as they relate to wind speed and direction in the St. Croix River study reach. The results of this study, along with published and unpublished wind data, were used to gain an understanding of wind-generated waves and their potential contribution to the mobilization of shoreline sediment (erosion of beach sediment and resuspension of nearshore sediment) as compared to the effects of waves generated by recreational boating activity.

METHODS

Wind direction and speed (magnitude), wave height, advective flow velocity and sediment mobilization were measured at 40 stratified, randomly selected (SRS) locations on the St. Croix River (figure 1). Advective flow is the movement of water down gradient due to gravity. The SRS locations were intended to represent an adequate number of sites to characterize shoreline mobilization in the study reach and were selected using a computerized random number generator. SRS sites were stratified according to boat-wave and foot-trampling criteria developed for the fixed-site survey transects. Site stratification and other field data collected during these efforts will be used in the future to integrate and synthesize findings and conclusions regarding potential contributing influences to shoreline erosion (table 1).

A handheld air-speed indicator (OMEGA model HH-F10) was used in the field to measure wind speed in miles per hour (mph). A compass was used to determine wind direction measured in number of degrees clockwise from the north azimuth. Advective flow velocity was measured at each site using an electronic flow meter (Marsh McBirney model 201D) attached to a wading rod

set at 0.5-feet water depth. Sediment traps were deployed nearshore in 1 foot of water for 1 minute at each site where wind waves were measurable (figure 2). Sediment samples were dried and weighed in the laboratory. Sediment samples represent a quantitative measure of the amount of sediment mobilized (eroded and resuspended) along the beach and nearshore zone. The 1-foot monitoring depth and 1-minute monitoring period were selected for comparison of the recreational boating controlled runs.

RESULTS AND DISCUSSION

Long-term wind speed and direction data specific to the St. Croix River were not available for the study reach. Therefore, data specific to the sampling day, as well as historical wind speed and direction statistical data recorded at Twin Cities International Airport in Minneapolis were used in the analysis.

At the Twin Cities International Airport in Minneapolis, wind speed and direction were measured from a standard 30-foot (10-meter) tower height. Wind speed was measured at 19.6 to 24.2 miles per hour from the southwest at 3:00 PM on September 18, 1997. A review of St. Paul's Holman Field data for that afternoon (17.3 to 24.2 miles per hour from the south) confirmed the relatively high wind speed measured at the Minneapolis airport (Greg Spoden, *pers. comm.*). On the Beaufort Wind Scale, the wind on monitoring day would have been qualitatively described as a fresh breeze (more than a moderate breeze but less than a strong breeze).

Wind speed and direction were measured at river level in the St. Croix River study reach. Wind speed ranged from 0 to 11.1 mph at the 40 SRS locations on September 18, 1997 (table 2). Wind direction was generally from the southwest (figure 3). An estimate of wind speed at 30 feet above the water surface (to directly compare to the airport data) can be made using the following empirical equation (adapted from Ferris, 1994):

Equation: $U_{30} = U_{(x)}(30/z)^{1/7}$

Where:

U_{30} = Wind speed at 30 feet above water surface.
$U_{(x)}$ = Measured wind speed.
z = Distance above water surface.
$U_{30} = 11.1(30/3)^{1/7}$

$U_{30} = 15.4$ mph

Measured wind speeds at both airports were significantly greater than the corrected values for winds measured at river level in the study reach. This suggested the river and island shorelines were somewhat sheltered from the wind. The predominant southwesterly winds, measured both at the airports and within the study reach on September 18, 1997, were essentially parallel with the river corridor. This orientation offered near optimum wind fetch potential within the bluff-lined river corridor (figure 1 and 3). Since wind direction and the orientation of the river

corridor's coincided to offer near optimum wind fetch potential, much of the sheltering may be attributed to the closely grouped islands and numerous trees within the study reach.

Wave heights measured in the study reach on September 18, 1998 ranged from 0 to 0.10 feet (table 2). Wave heights of this magnitude are relatively small compared to waves generated by many recreational boats or waves observed on Lake St. Croix on days with similar wind conditions. Recreational boating activity was very low on monitoring day and therefore recreational boat waves did not interfere or complicate the measurement of wind-generated waves.

Wave heights and wind speed were graphed to identify trends or relationships (figure 4). Although there appears to be a positive relationship between wind speed and wave height, the R^2 value is relatively low and there was not a full range of wave height values to properly assess the relationship.

The amount of sediment mobilized and redeposited within the sediment traps was small at all sites (figures 5 and 6, table 2). Figure 5 illustrates the relationship of wave height to sediment mobilized. Sediment trap results at all 40 SRS locations were well below 1 gram per minute. Figure 6 illustrates similar results in a comparison of wind speed to sediment trap results. In the field, wind-generated waves were observed to impinge tangentially on most shorelines. Only at the downstream end of islands did waves impinge squarely on the shoreline.

A comparison of sediment trap results for wind-generated waves and controlled recreational boat-generated waves clearly illustrates the relative erosion and resuspension potential (figure 7). As shown in figure 7, all wind-generated wave heights were less than the sediment mobilization threshold of 0.4-feet. Waves less than 0.4-feet in height, whether boat or wind-generated, apparently do not significantly mobilize shoreline sediments.

Winds measured on monitoring day at both airports were well above the average September wind speed of 10 miles per hour (figure 8).Wind direction was near optimum for the development of long wind-fetch generated waves. Duration analysis suggests wind speeds measured on monitoring day were faster than wind speeds during 90% of the year (figure 8)(U.S. Weather Bureau, 1968).

With narrow river channels and closely grouped islands in the study area, wind-fetch potential is limited and a very high wind speed would be necessary to generate waves greater than a wave height of 0.4-feet. To further investigate the wind-generated wave potential for mobilizing sediments, a hypothetical situation can be used to calculate the wind speed necessary to generate a wave greater than the sediment mobilization threshold. Assuming a constant wind speed directly towards shore and a wind fetch of 0.20 miles (approximately 1000 feet between islands), an empirical equation adapted from Bhowmick (1978) can be used to estimate the wind speed necessary to generate a wind wave of 0.4 feet.

Equation: $H = (3.048 \times 10^{-2}) \times U^{1.13} \times F^{0.435}$

Where:	H = wave height	0.4 feet
	U = wind speed in mph	To be calculated
	F = effective wind fetch	0.20 miles

Solving for U: $U = (H / (3.048 \times 10^{-2}) (F^{0.435}))^{.88}$

$U = (0.4 / (3.048 \times 10^{-2}) (0.20)^{0.435})^{.88}$

$U = 18$ mph

Based on the wind speeds measured on monitoring day, the airport wind speeds were about 2 times greater than wind speeds at river level. Therefore, a wind speed of 18 mph at river level would be equivalent to approximately a 36 mph wind at the airports. Wind speeds greater than 36 mph occur less than 1 percent of the year (figure 8) which is equal to the 2-minute maximum wind speed measured for the month of September in 1988 (National Climatic Data Center, 1996). Monthly 2-minute maximum wind speeds range from 33 to 51 mph. Based on this analysis, it would be possible, but a relatively rare and short-term event, for wind-generated waves to surpass the 0.4-foot sediment mobilization threshold within the study reach. In contrast, recreational boats within the study reach generate waves greater than 0.4-feet on weekends, holidays and evenings during the May to September boating season (based on controlled run studies and boating use patterns documented in earlier chapters).

CONCLUSIONS

The results of this analysis suggest that the St. Croix River study reach is partially sheltered from most winds. Wind-generated wave heights measured in the field were much less than the 0.4-foot mobilization threshold identified in the controlled run studies. Wind-generated waves on monitoring day mobilized small quantities of shoreline sediment at study sites. Wind-generated waves greater than the 0.4-foot mobilization threshold occur rarely within the study reach.

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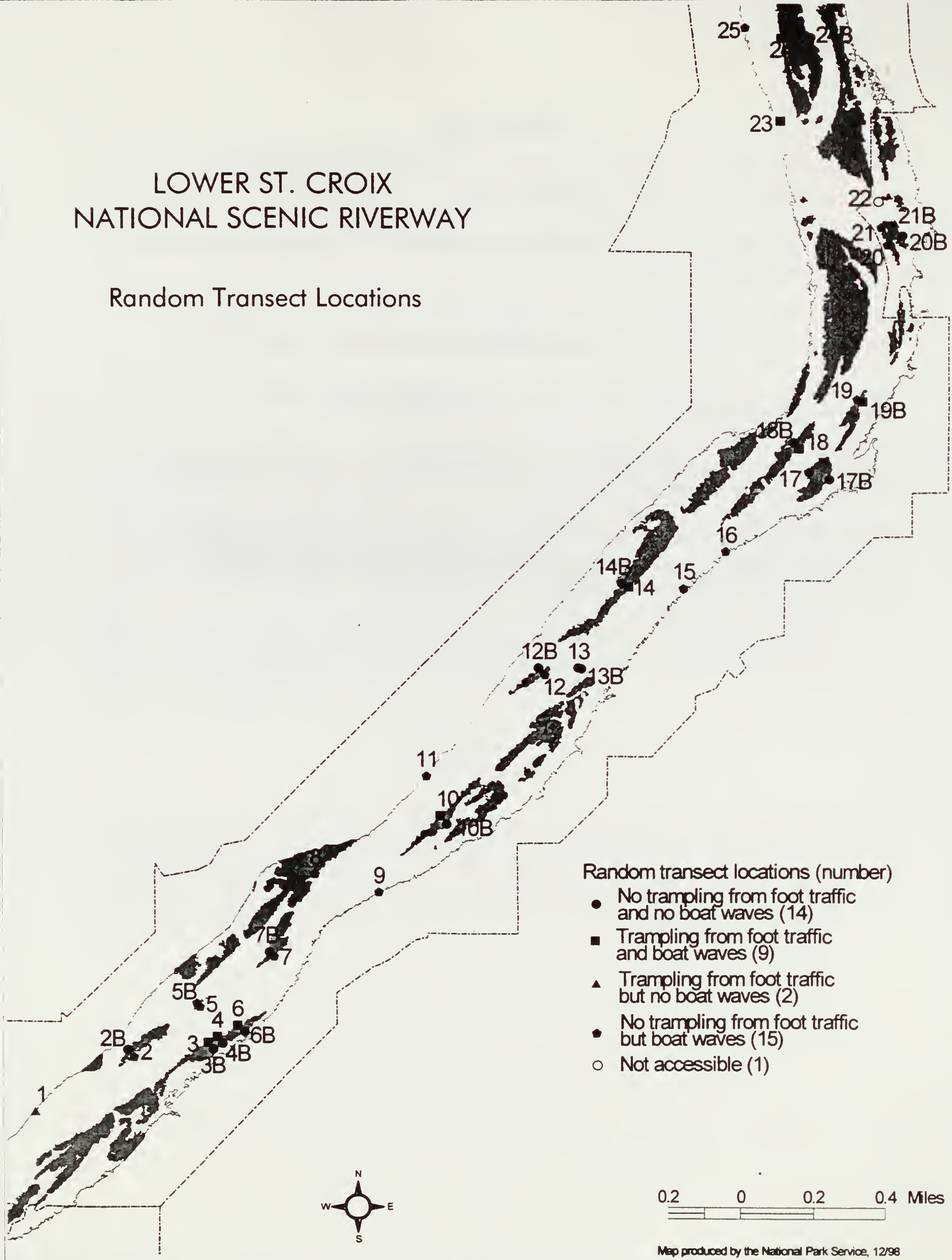

Figure 1. Study Reach Location Map and Stratified Random Sampling Site Locations.

PROTOTYPE FOR SEDIMENT TRAP

(not to scale)

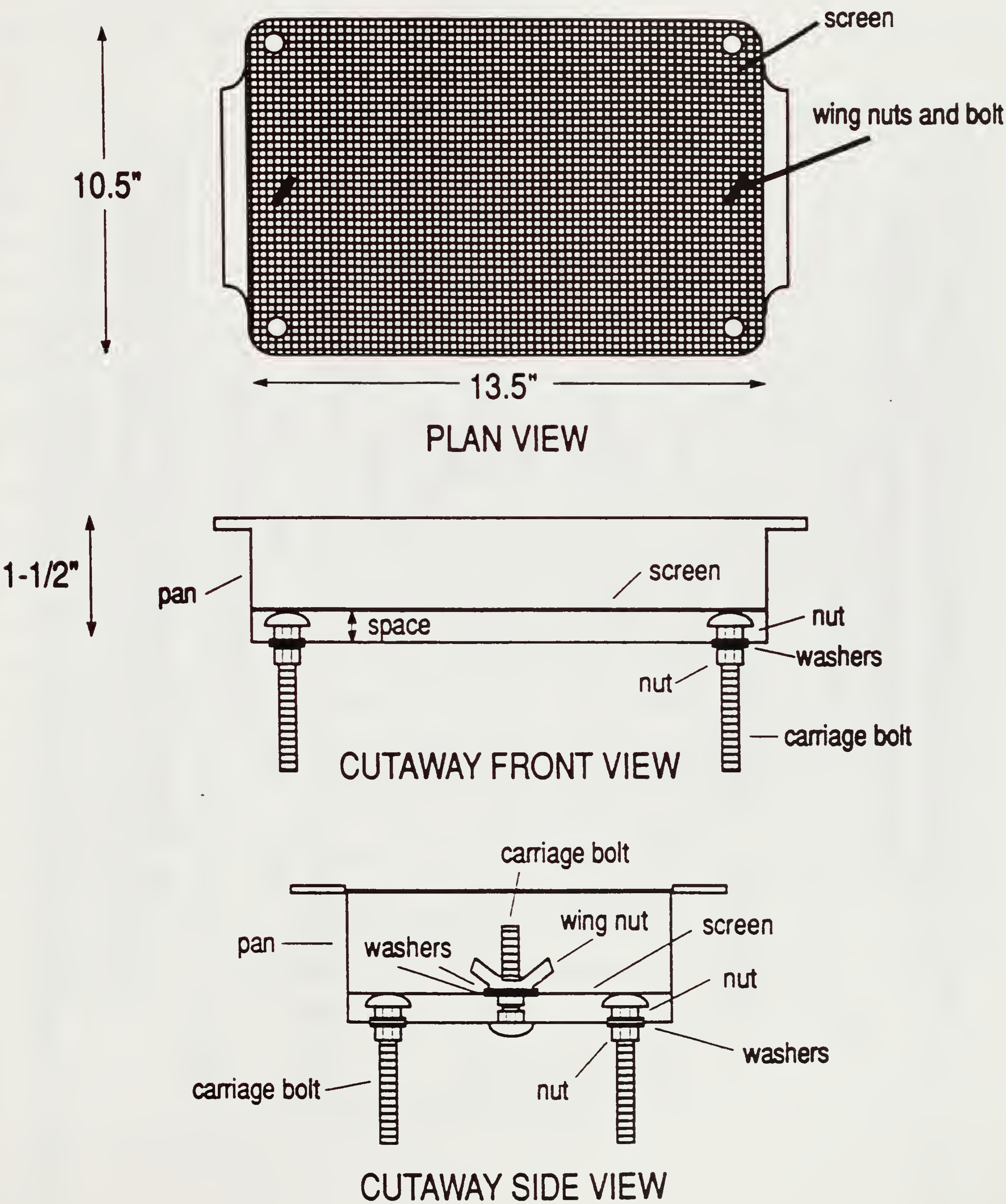

Figure 2. Sediment Trap Schematic.

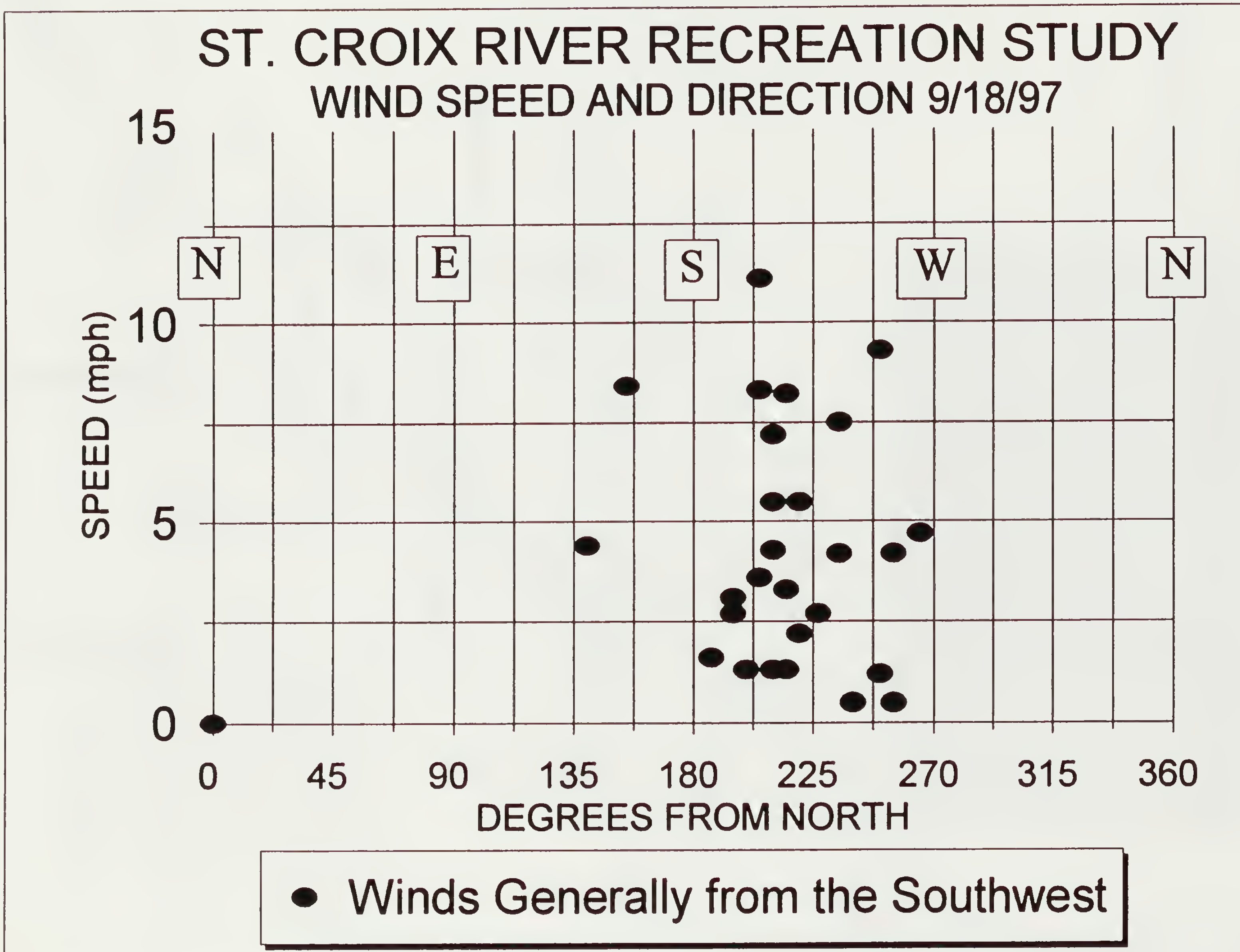

FIGURE 3. Wind Speed and Direction as Measured on September 18, 1997.

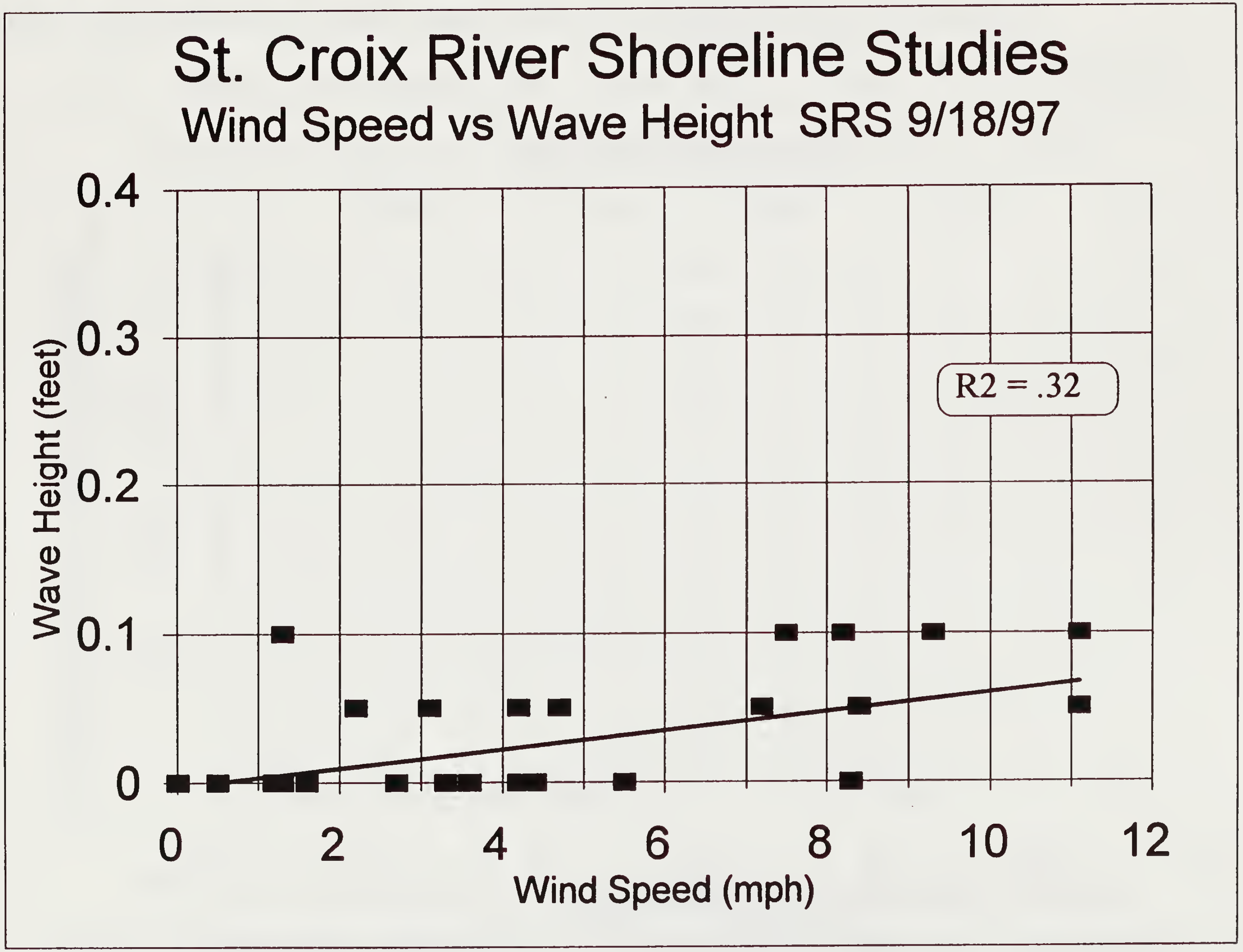

FIGURE 4.Wind Speed and Wave Height Comparisons.

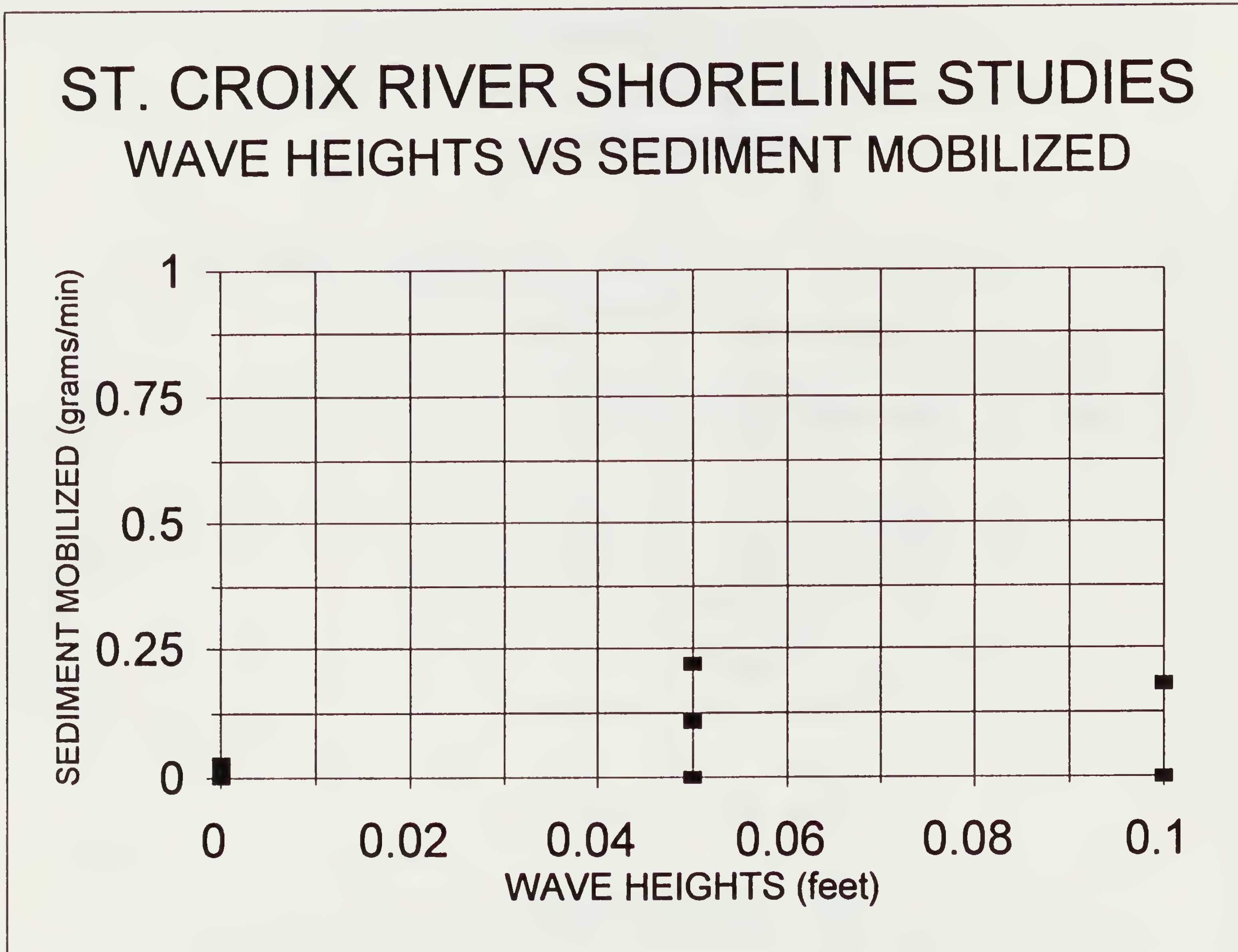

FIGURE 5. Wind-Generated Wave Heights and Sediment Mobilization Comparisons.

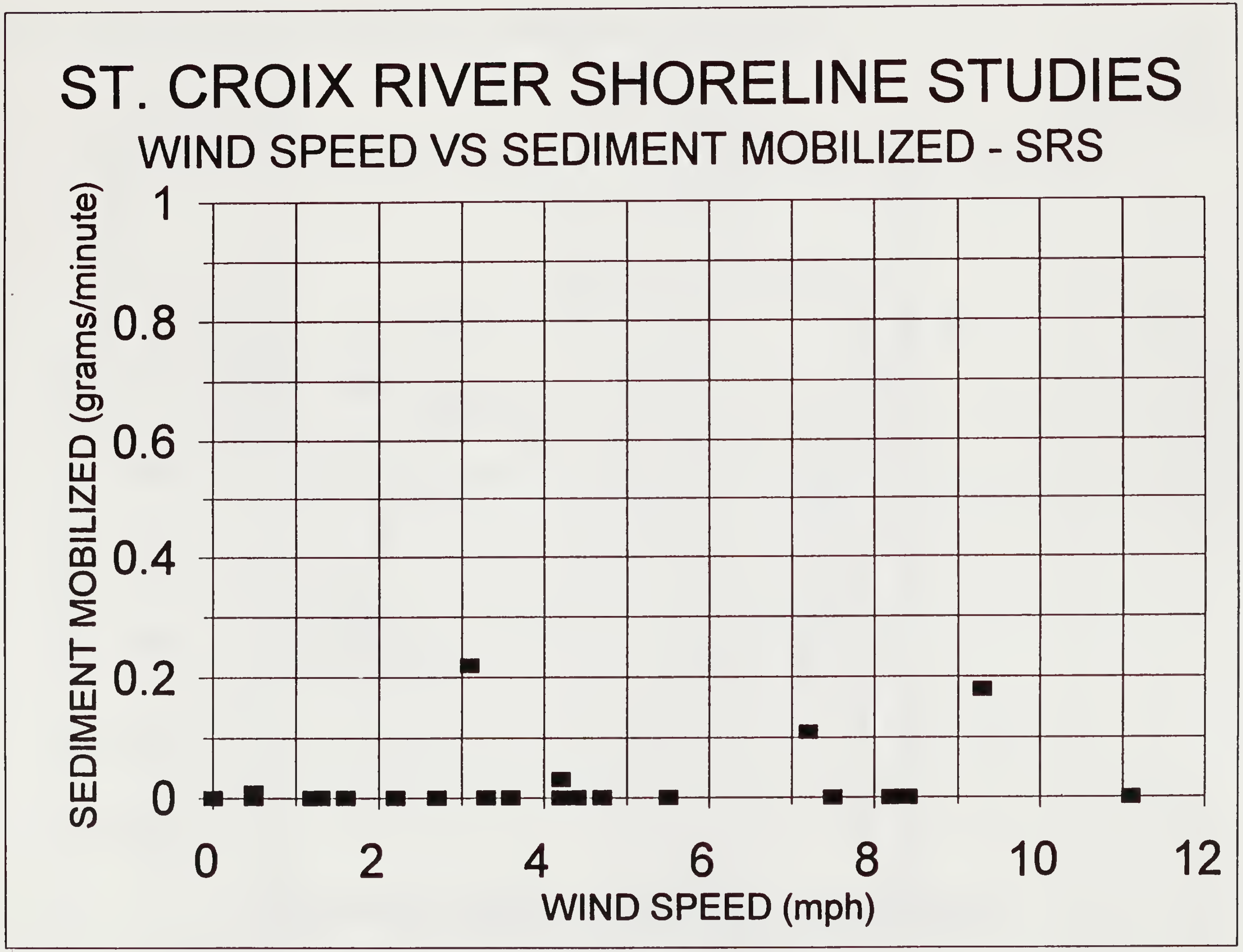

FIGURE 6. Wind Speed and Sediment Mobilization Comparisons.

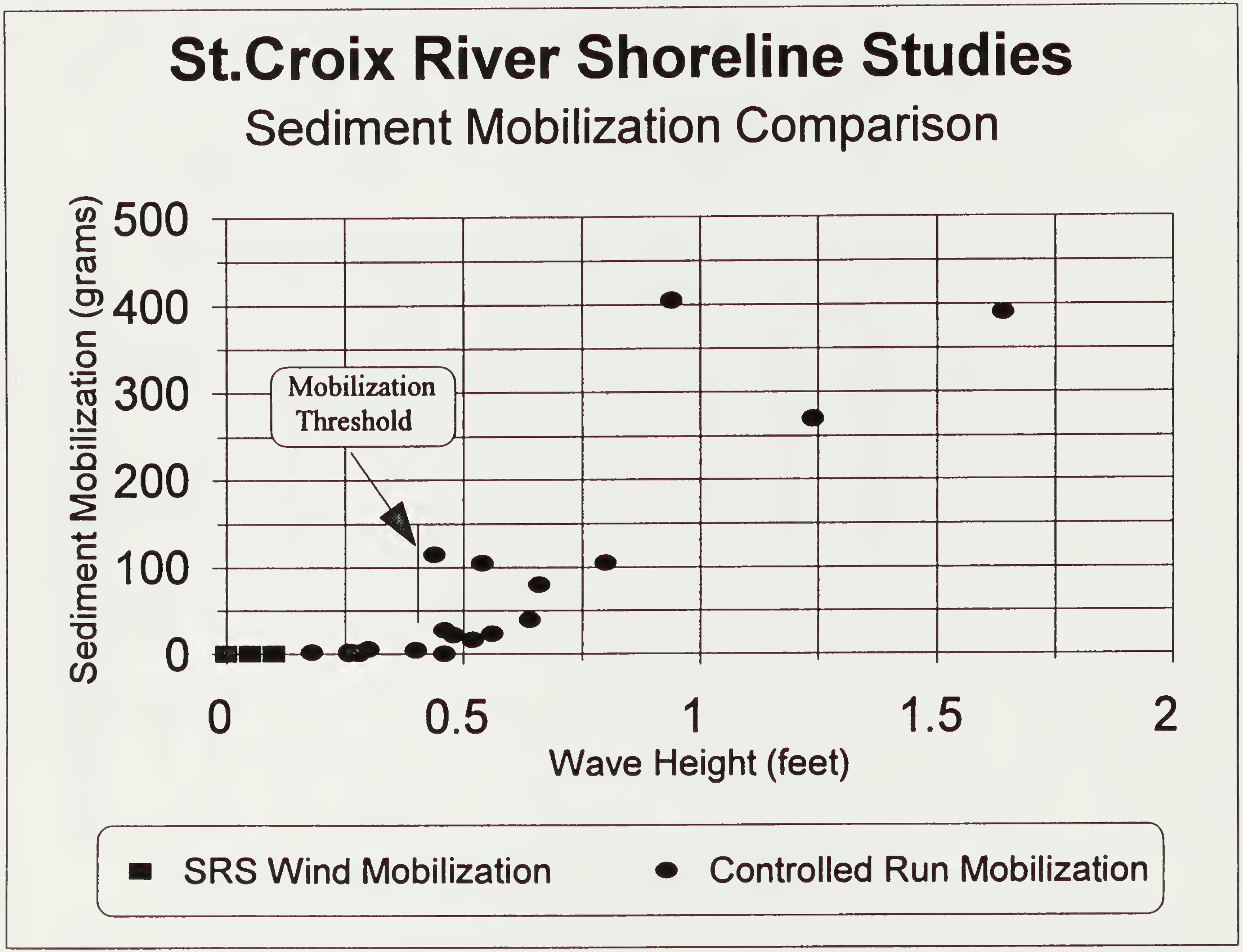

FIGURE 7.SRS Wind and Controlled Run Mobilization Comparisons.

Monthly Prevailing Direction and Mean Speed (miles per hour) of Wind

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Speed	11	11	12	13	12	11	9	9	10	11	12	11
Direction	NW	NW	NW	NW	SE	SE	S	SE	S	SE	NW	NW

Annual Percentage Frequency (Duration) of Wind by Speed Groups and the Mean Speed (in miles per hour)

Speed Group (in mph)	0 to 3	4 to 7	8 to 12	13 to 18	19 to 24	25 to 31	32 to 38	39 to 46	47 and Over	Mean Speed
Duration %	8	21	34	28	9	2	(1)	(1)	(1)	11.2

Note: (1) less than 1 percent

Fastest Mile and Direction of Wind (miles per hour)

Month	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Speed	47	52	56	58	56	63	92	57	50	73	60	52
Direction	NW	NW	SW	N	NW	NW	W	NW	NW	S	SW	W

Note: Data are for 50 years of record

Figure 8. Wind Data Compiled from the National (US) Weather Service.

Table 1. Stratified Random Site (SRS) Locations and Descriptions.

ST. CROIX RIVER SEPT 18, 1997
RANDOM TRANSECT LOCATIONS

TRANSECT	RIVER MILE	STATE	FIELD CLASS	COMMENTS
1	25.17	M	NBYT	M = MINNESOTA SIDE OF MAIN CHANNEL
2	25.44	M	YBNT	W = WISCONSIN SIDE OF MAIN CHANNEL
2B	25.44	MB	NBNT	MB = MINNESOTA BACKWATER/SIDE CHANNEL
3	25.60	W	YBYT	WB = WISCONSIN BACKWATER /SIDE CHANNEL
3B	25.60	WB	NBNT	YB = YES BOATS
4	25.61	W	YBYT	NB = NO BOATS
4B	25.61	WB	NBNT	YT = YES TRAMPLING
5	25.63	M	YBNT	NT = NO TRAMPLING
5B	25.63	MB	YBNT	
6	25.68	W	YBYT	
6B	25.68	WB	NBNT	
7	25.86	M	YBNT	
7B	25.86	MB	NBNT	
8	26.10	M	YBNT	
9	26.19	W	YBNT	
10	26.43	W	YBYT	
10B	26.43	WB	NBNT	
11	26.46	M	YBNT	
12	26.85	M	YBNT	
12B	26.85	MB	NBNT	
13	26.97	W	NBNT	
13B	26.97	WB	NBNT	
14	27.15	M	YBYT	
14B	27.15	MB	NBNT	
15	27.21	W	YBNT	
16	27.40	W	YBNT	
17	27.67	W	YBNT	
17B	27.67	WB	NBNT	
18	27.69	M	YBYT	
18B	27.69	MB	NBNT	
19	27.91	W	YBNT	
19B	27.91	WB	NBNT	
20	28.30	W	YBNT	
20B	28.30	WB	NBNT	
21	28.32	W	YBNT	
21B	28.32	WB	NBYT	
22	28.39	W	NOT ACCESSIBLE	
23	28.64	M	YBYT	
24	28.88	W	YBYT	
24B	28.88	WB	NBNT	
25	28.95	M	YBNT	

St. Croix River Study Random Wind,H2O Velocity, Wave Height, Suspended Sediments (9/18/97)										
	SITE	CONDITIONS	WIND SPEED		DIRECTION	FLOW VEL	WAVE HT	SAMPLED	SEDIMENT	
			MPH		DEGREES	FT/SEC	FEET		GRAMS/MIN	
1	1	NBYT	1.3	200	N200W	-0.10	0.00	no	0.00	
2	2	YBNT	1.6	187	N187W	0.07	0.00	no	0.00	
3	2B	NBNT	1.6	187	N187W	0.07	0.00	no	0.00	
4	3	YBYT	4.2	235	N235W	0.00	0.00	no	0.00	
5	3B	NBNT	0	0	0	0.07	0.00	no	0.00	
6	4	YBYT	4.2	235	N235W	0.26	0.00	yes	0.03	
7	4B	NBNT	0	0	0	0.12	0.00	no	0.00	
8	5	YBNT	4.3	210	N210W	0.11	0.00	no	0.00	
9	5B	YBNT	4.3	210	N210W	0.03	0.00	no	0.00	
10	6	YBYT	4.2	235	N235W	0.00	0.00	no	0.00	
11	6B	NBNT	0	0	0	0.24	0.00	no	0.00	
12	7	YBNT	2.7	227	N227W	0.04	0.00	no	0.00	
13	7B	NBNT	2.7	227	N227W	0.04	0.00	no	0.00	
14	8	YBNT	3.6	205	N205W	0.04	0.00	no	0.00	
15	9	YBNT	0	0	0	0.18	0.00	no	0.00	
16	10	YBYT	0.5	240	N240W	0.26	0.00	yes	0.01	
17	10B	NBNT	0.5	240	N240W	0.07	0.00	no	0.00	
18	11	YBNT	3.3	215	N215W	0.16	0.00	no	0.00	
19	12	YBNT	7.2	210	N210W	0.53	0.05	yes	0.11	
20	12B	NBNT	5.5	210	N210W	0.21	0.00	no	0.00	
21	13	NBNT	4.2	255	N255W	0.12	0.05	no	0.00	
22	13B	NBNT	0.5	255	N255W	-0.02	0.00	no	0.00	
23	14	YBYT	5.5	220	N220W	0.10	0.00	no	0.00	
24	14B	NBNT	1.3	215	N215W	0.04	0.00	no	0.00	
25	15	YBNT	2.2	220	N220W	0.35	0.05	yes	0.00	
26	16	YBNT	4.7	265	N265W	0.21	0.05	no	0.00	
27	17	YBNT	9.3	250	N250W	0.36	0.10	yes	0.18	
28	17B	NBNT	1.2	250	N250W	-0.04	0.00	no	0.00	
29	18	YBYT	8.2	215	N215W	0.08	0.10	no	0.00	
30	18B	NBNT	1.3	210	N210W	0.09	0.10	no	0.00	
31	19	YBNT	7.5	235	N235W	0.21	0.10	no	0.00	
32	19B	NBNT	0	0	0	0.08	0.00	no	0.00	
33	20	YBNT	11.1	205	N205W	-0.04	0.05	no	0.00	
34	20B	NBNT	8.3	205	N205W	0.03	0.00	no	0.00	
35	21	YBNT	11.1	205	N205W	-0.03	0.10	no	0.00	
36	21B	NBYT	8.3	205	N205W	0.00	0.00	no	0.00	
37	23	YBYT	4.4	140	N140W	0.21	0.00	no	0.00	
38	24	YBYT	3.1	195	N195W	0.26	0.05	yes	0.22	
39	24B	NBNT	2.7	195	N195W	-0.03	0.00	no	0.00	
40	25	YBNT	8.4	155	N155W	-0.04	0.05	no	0.00	

TABLE 2. Data Collection Results.

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 9

ADVECTIVE FLOW VELOCITIES AND SHORELINE EROSION

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Division of Waters

July 22, 1999

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ABSTRACT

Shoreline erosion is perceived by many users and managers of the St. Croix River as a growing natural resource problem. Channel bottom and vertical flow velocity profiles were developed over a range of flow conditions at fixed survey sites in the study area. Most nearshore channel bottom velocities were below critical velocity values for the mean shoreline particle size. Vertical velocity profiles measured approximately 20 feet from the waterline indicate higher velocities in the water column than those measured at the channel bottom and nearshore. An Acoustic Doppler Flow Meter (ADFM) was used to compare normal and flood-flow velocities in the river channel. Flood-flow velocities were generally a bit higher than normal flow velocities and more often greater than the critical velocity for the shoreline mean particle size. Velocities were lower nearshore and near the channel bottom. At 40 stratified, randomly selected sites, advective flow velocities were measured and sediment traps were used to collect samples under normal flow conditions. Only very small amounts of sediment were collected in sediment traps.

INTRODUCTION AND PURPOSE

Shoreline erosion is often an episodic event, a phenomenon influenced by numerous interrelated contributing influences acting over a range of temporal and spatial scales. Both human-induced and natural influences contribute to shoreline erosion. The influences investigated for the St. Croix River shoreline studies include advective flow velocity, boat-generated waves, foot-traffic trampling and wind-generated waves. Advective flow is the movement of water down gradient due to gravity. To characterize normal and high flow event contributions to shoreline erosion, advective flow velocities were measured at 14 shoreline survey sites. Both channel bottom and vertical velocity profiles were developed over a range of flow conditions. Advective flow velocities were also measured using an Acoustic Doppler Flow Meter during normal and flood conditions (MCES, 1998). Sediment traps were employed to measure sediment mobilization nearshore during normal flow conditions.

METHODS

To gain an objective perspective on advective flow velocity and its potential contribution to shoreline erosion, a variety of quantitative methods were used over a range of flow conditions. At the survey sites, both bottom and vertical velocity profiles were developed (figure 1). Bottom velocity profiles were measured using a Marsh McBirney 201D Flow Meter and a wading rod set 0.5 feet from the channel bottom. Measurements were taken every two feet from the water line to a water depth of approximately three feet (table 1). Vertical velocity profiles were measured in 0.5 foot increments from the channel bottom to the top of the water column in approximately three feet of water, which was approximately 20 feet from shore (table 2).

Flow velocities were also collected using an Acoustic Doppler Flow Meter (ADFM) by the

Metropolitan Council Environmental Services (MCES) under normal (Stillwater Gage water level 676.09 1912 NGVD on 11/24/98) and high flow conditions (Stillwater Gage water level 682.89 1912 NGVD on 4/13/98) at the survey sites (figure 1). ADFM profiles were obtained from a boat piloted across the channel perpendicular to flow near the survey sites. Normal and high flow transects were completed in approximately the same channel location. Field data were processed mathematically to produce representative vertical velocity profiles at 50-foot increments across the channel.

Sediment trap sampling locations and monitoring period were selected in order to compare their results with the results from the wind-generated and boat-generated wave studies. Using a random number generator, 40 stratified, randomly selected sampling (SRS) sites were located (figure 2). At each SRS site, advective flow velocities were measured 0.5 feet from the channel bottom in one foot of water. A sediment trap was placed on the channel bottom in one foot water for a one minute monitoring interval. (figure 3). High water clarity allowed researchers to observe that there were no sediment particles (wash or bed load) in the water column when velocities were less than 0.25 ft/sec. No sediment samples were collected when velocities were less than the 0.25-ft/sec threshold value. Sediment samples were dried and weighed back in the laboratory.

RESULTS AND DISCUSSION

Bottom Flow Velocities Profiles

Bottom flow velocities ranged from 0 to 0.60 ft/sec at the fixed survey sites. Generally, bottom flow velocities were relatively slow. Flow velocities greater than 0.4 ft/sec were measured at only 13 of the 49 channel bottom profiles. Bottom flow velocities during normal flow conditions were highest at fixed survey sites 2A, 5, and 11B.

A Hjulstrom diagram (figure 4) illustrates three methods developed by researchers and compiled by an American Society of Civil Engineers (ASCE) Task Committee to describe the relationship between sediment particle size and the critical velocity required to move a sediment particle. The mean particle size for shoreline sediments on the St. Croix River was calculated to be 0.4 millimeters or 0.016 inches. The particle size distribution and the method for calculating the mean particle size is shown in figure 5. Using the Hjulstrom diagram, it is evident that most of the measured flow velocities were below the lower range of the critical velocity curve for a particle 0.4 millimeters in diameter. Likewise, most flow velocities were below the Mavis and Laushey as well as the Shields bottom critical velocity which are also shown in the diagram. This analysis suggests that advective flow velocities nearshore are generally not great enough to move the mean shoreline sediment particles.

Vertical Flow Velocity Profiles

The vertical flow velocity profiles measured approximately 20 feet distance from the waterline

indicate that flow velocities are higher off shore than those measured nearshore (table 1 and 2). Advective flow velocities are reduced nearshore because of friction between the water and nearshore sediments. If nearshore sediments are eroded or resuspended, then redeposited further off shore (as in the case of wind and recreational boat-generated waves), sediments would be subject to higher flow velocities and experience a greater chance of being entrained into the main channel bed load. Redeposited sediments would likely have a lower bulk density than other bottom sediments, which suggests a greater chance of entrainment into the main channel bed load.

The vertical velocity profiles generally indicate that flow velocities near the channel bottom are less than those found higher in the water column (figure 6). Flow velocities are great enough to mobilize 0.4-millimeter sediment particles (representing the beach and nearshore mean particle size) at most sites under most flow conditions at a station 20 feet from the waterline. No additional sediment samples were taken in waters 3 feet in depth or greater for particle size analysis to determine if the mean particle size offshore is greater than the mean particle size nearshore.

Acoustic Doppler Flow Meter Velocity Measurements

The ADFM vertical velocity profiles confirm velocity distribution first described by the nearshore vertical and channel bottom velocity profiles. Flow velocities are higher the farther measurements are taken from shore and off the channel bottom. This observation is in agreement with measurements made in other river studies (Gordon *et al.* 1992).

A comparison of normal and high flow vertical velocity profiles illustrates that velocities are higher in the channel during flood conditions (figure 7 and appendix 3). Velocities near the channel bottom are variable but tend to be lower than those measured higher in the water column. Advective flow velocities during high flow events are capable of eroding shoreline sediments in the study area.

Stratified Random Sampling Sediment Trap Results

Sediment samples collected at the 40 SRS sites were dried and weighed in the laboratory (table 4). Water levels on monitoring day were at normal summer elevations (Stillwater Gage water level 675.98 1912 NGVD on 9/18/97). Sediment samples all weighed less than 1 gram, much less than sediment trap results from the both the controlled run and normal boating activity studies when wave heights were greater than 0.4 feet. Most flow velocities were less than the critical velocities represented on the Hjulstrom Diagram (see the Hjulstrom, Mavis and Laushey, Shields critical velocity curves in figure 4). Sediment trap results confirmed the hypothesis that only a very small amount of sediment would be collected based on the measured velocities (figure 9) and the critical velocities represented in the Hjulstrom Diagram (figure 4).

Flood Flows

A comparison of the discharge hydrograph at St. Croix Falls with the stage hydrograph at

Stillwater reveals similar peaking patterns suggesting a direct relationship between discharge and stage during higher flow events (Appendixes 1 and 2). Ranking of the annual peak discharges shows that the top 10 floods have occurred since 1944 (figure 11). The top 10 annual peak discharges were distributed fairly evenly over the last 5 decades. However, 3 of the top 10 events have occurred since shoreline erosion emerged as an issue of concern on the St. Croix River in the mid-1980s. Since the shoreline studies began in 1995, 2 of the top 10 events have occurred on the St. Croix River. Annual flood discharge peaks measured at the USGS gage at St. Croix Falls are highly variable. A best fit line through the data points suggest peaks have trended slightly upward since 1910 but the r^2 value is low (figure 10). The same peak discharge analysis using a subset of the stage gage data from 1950 to 1994 showed a slightly downward trend.

In addition to annual discharge peaks, the duration (length of time), frequency, and rate of rise and fall are other flood characteristics that may have some bearing on the effects a specific flood may have on a particular reach of river shoreline. A statistical trend analysis of the Stillwater Gage stage data from 1972 to 1994 was completed based on parametric statistics using the "Indicators of Hydrologic Alteration" (IHA) software (Nature Conservancy 1997) (appendix 4). The period of 1972 to 1994 was selected because the Corps had maintained the same operating curves at Lock and Dam 3 throughout this period of time.

The Indicators of Hydrologic Alteration software automatically plots a best fit line using standard linear regression statistical techniques. It also calculates the r^2 and p values for the data. An r^2 value of 1 indicates a perfect linear relationship between the independent and dependent variables while an r^2 of -1 indicates an inverse relationship. R^2 values were very low (near zero) for all linear regressions of the hydrologic indicators (Appendix 4). This would suggest that the variability of the data can not be explained by the relationship between the independent variable time and the dependent variable stage (water level).

P values provide a measure of probability that there is a statistically significant relationship between the independent and dependent variables. Typically values of p less than .01 or .05 are selected to identify statistically significant relationships. P values were greater than .25 for all but the 90-Day Minimum Stage regression analysis. These results suggest that there are no statistically significant trends for most of the regression analyses performed by the Indicators of Hydrologic Alteration trend analysis, including all flood flow analyses (Appendix 4).

The 90-day Minimum Stage trend analysis had an r^2 value of .169 and a p value of less than .05. The results suggest a statistically significant trend upward from 1972 to 1994 for the 90 day minimum stage. Overall, flood flow characteristics as measured by the IHA analyses showed no trends that would likely lead to a systemic acceleration and proliferation of shoreline erosion.

Contributing influences to shoreline erosion operate at different temporal and spatial scales and may only be expressed in connection with other factors or events. Additional contributing factors, such as the density and distribution of shoreline vegetation, geomorphic position, sediment particle size, sediment bulk density, and recreational boat waves, all have the capacity

to influence how much shoreline erosion is observed following a particular flood event. In short, shoreline erosion that is perceived to be attributable to flooding, may be due to a combination of other contributing influences that were not readily observable.

CONCLUSIONS

Most nearshore channel bottom velocities were below critical velocity values for the mean shoreline particle size. Vertical velocity profiles measured approximately 20 feet from the waterline indicate higher velocities in the water column than those measured at the channel bottom and nearshore. Flood flow velocities were generally a bit higher than normal flow velocities and were more often greater than the critical velocity for the shoreline mean particle size. Only very small amounts of sediment were collected in sediment traps. Flood events, in conjunction with other contributing influences, may contribute to shoreline erosion.

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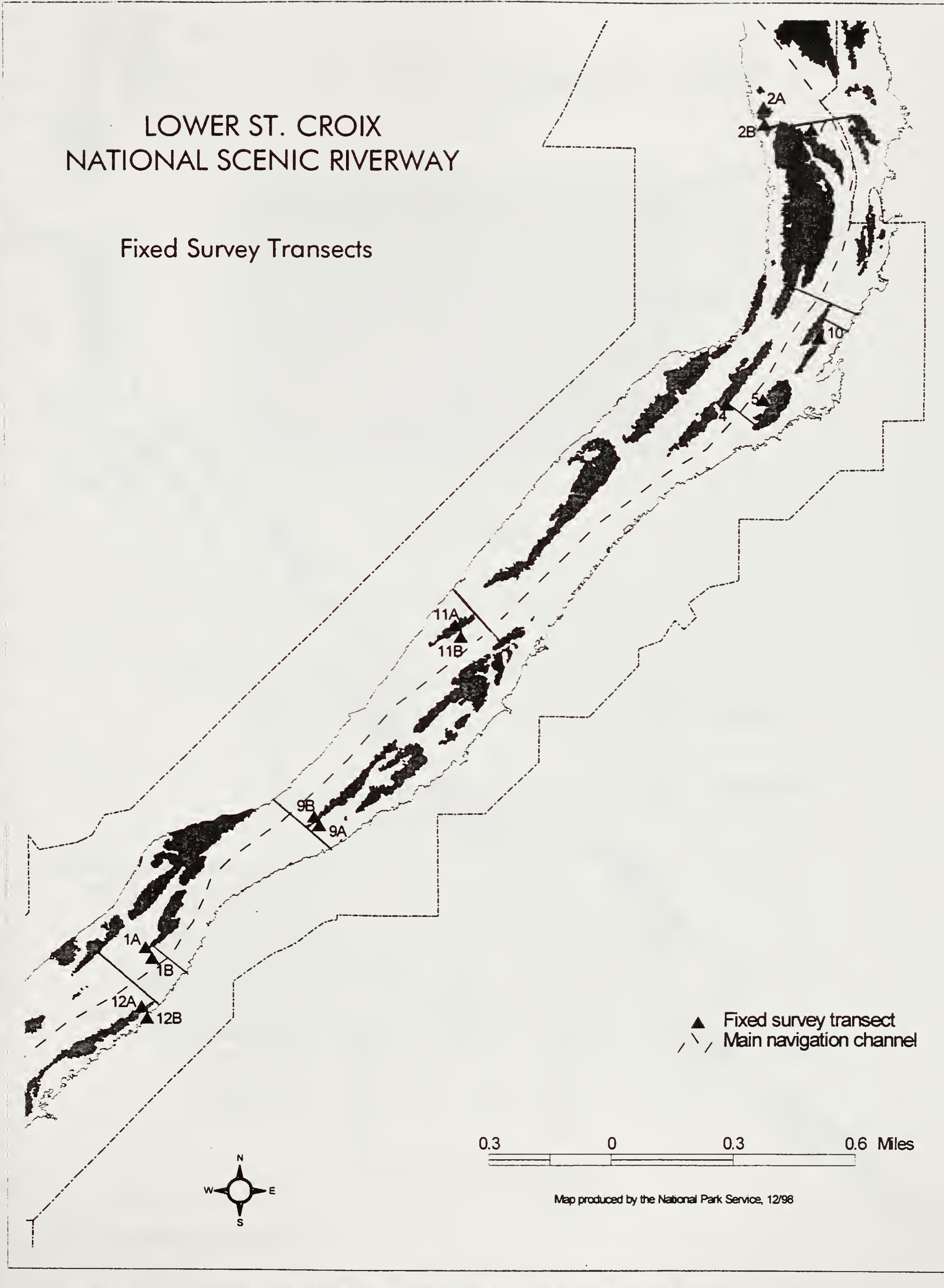


Figure 1. **Study Area Location Map and Fixed Survey Transect Locations.**

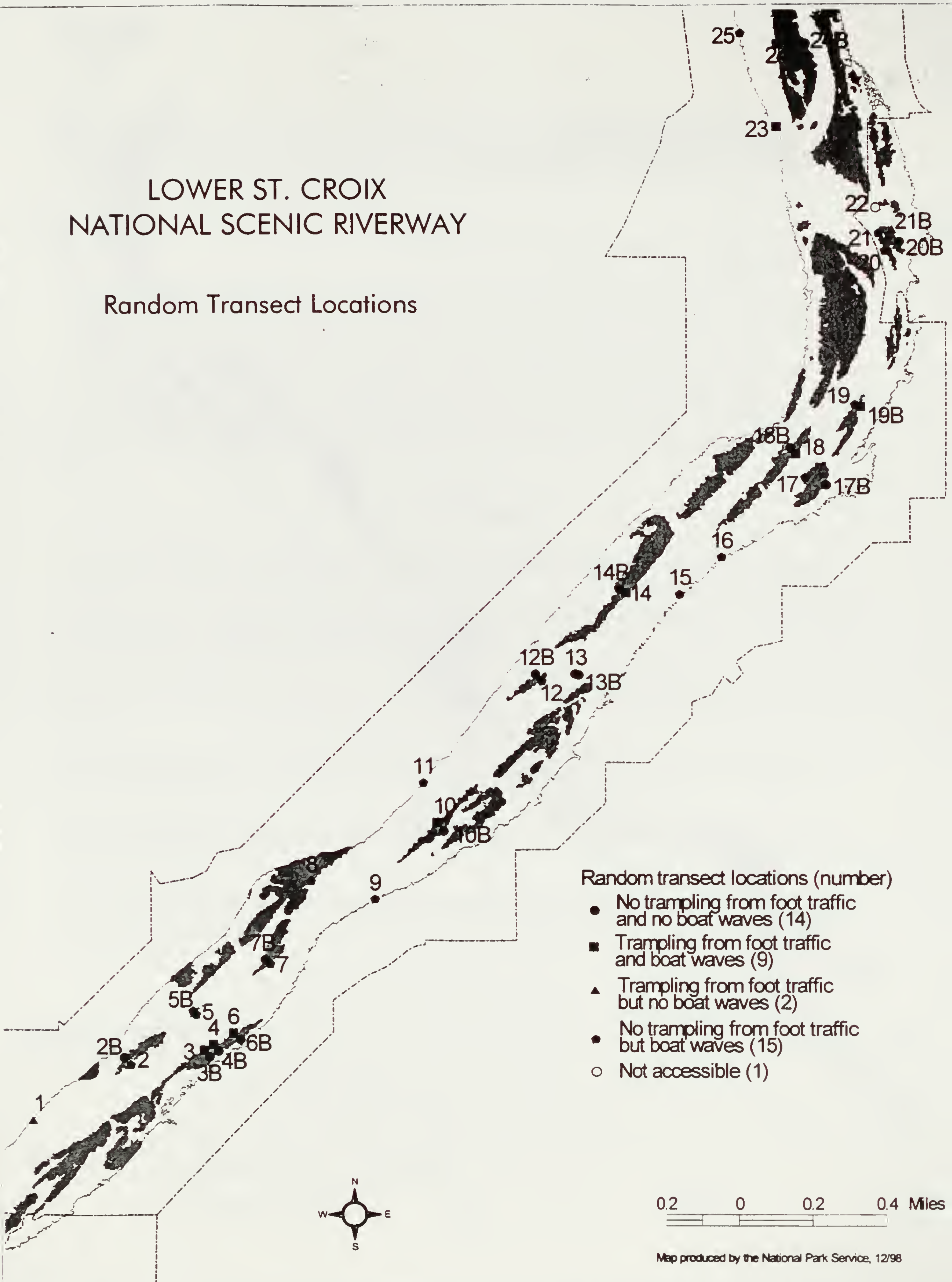
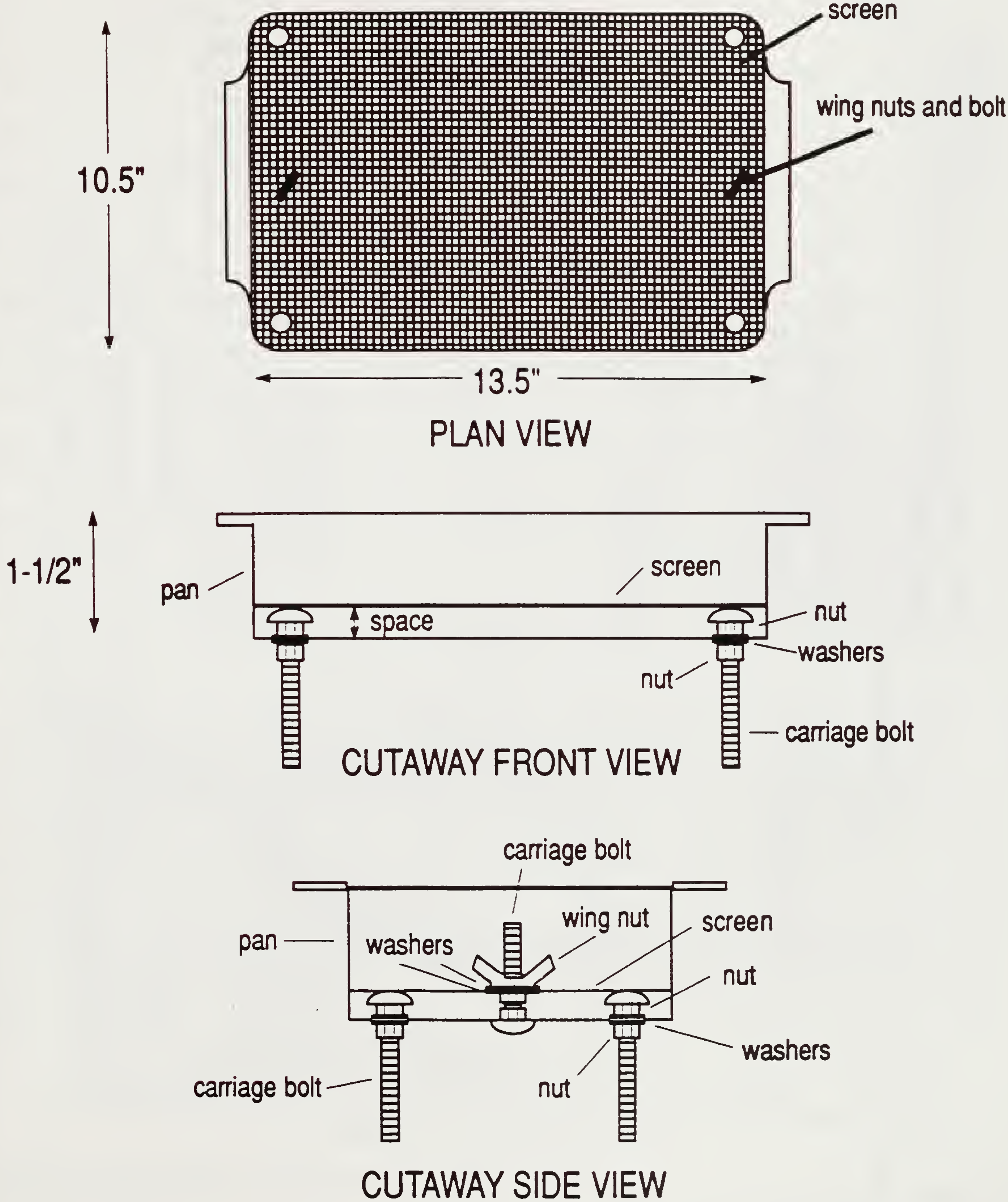


Figure 2. Stratified, Randomly Selected (SRS) Sampling Locations.

PROTOTYPE FOR SEDIMENT TRAP

(not to scale)



F-3. Sediment Trap Diagram.

Size				Approximate Sieve Mesh Openings per Inch		
Millimeters		Microns	Inches	Tyler	U.S. Standard	Class
4000–2000			160–80			Very large boulders
2000–1000			80–40			Large boulders
1000–500			40–20			Medium boulders
500–250			20–10			Small boulders
250–130			10–5			Large cobbles
130–64			5–2.5			Small cobbles
64–32			2.5–1.3			Very coarse gravel
32–16			1.3–0.6			Coarse gravel
16–8			0.6–0.3	$2\frac{1}{2}$		Medium gravel
8–4			0.3–0.16	5	5	Fine gravel
4–2			0.16–0.08	9	10	Very fine gravel
2–1	2.00–1.00	2000–1000		16	18	Very coarse sand
$1-\frac{1}{2}$	1.00–0.50	1000–500		32	35	Coarse sand
$\frac{1}{2}-\frac{1}{4}$	0.50–0.25	500–250		60	60	Medium sand
$\frac{1}{4}-\frac{1}{8}$	0.25–0.125	250–125		115	120	Fine sand
$\frac{1}{8}-\frac{1}{16}$	0.125–0.062	125–62		250	230	Very fine sand
$\frac{1}{16}-\frac{1}{32}$	0.062–0.031	62–31				Coarse silt
$\frac{1}{32}-\frac{1}{64}$	0.031–0.016	31–16				Medium silt
$\frac{1}{64}-\frac{1}{128}$	0.016–0.008	16–8				Fine silt
$\frac{1}{128}-\frac{1}{256}$	0.008–0.004	8–4				Very fine silt
$\frac{1}{256}-\frac{1}{512}$	0.004–0.0020	4–2				Coarse clay
$\frac{1}{512}-\frac{1}{1024}$	0.0020–0.0010	2–1				Medium clay
$\frac{1}{1024}-\frac{1}{2048}$	0.0010–0.0005	1–0.5				Fine clay
$\frac{1}{2048}-\frac{1}{4096}$	0.0005–0.00024	0.5–0.24				Very fine clay

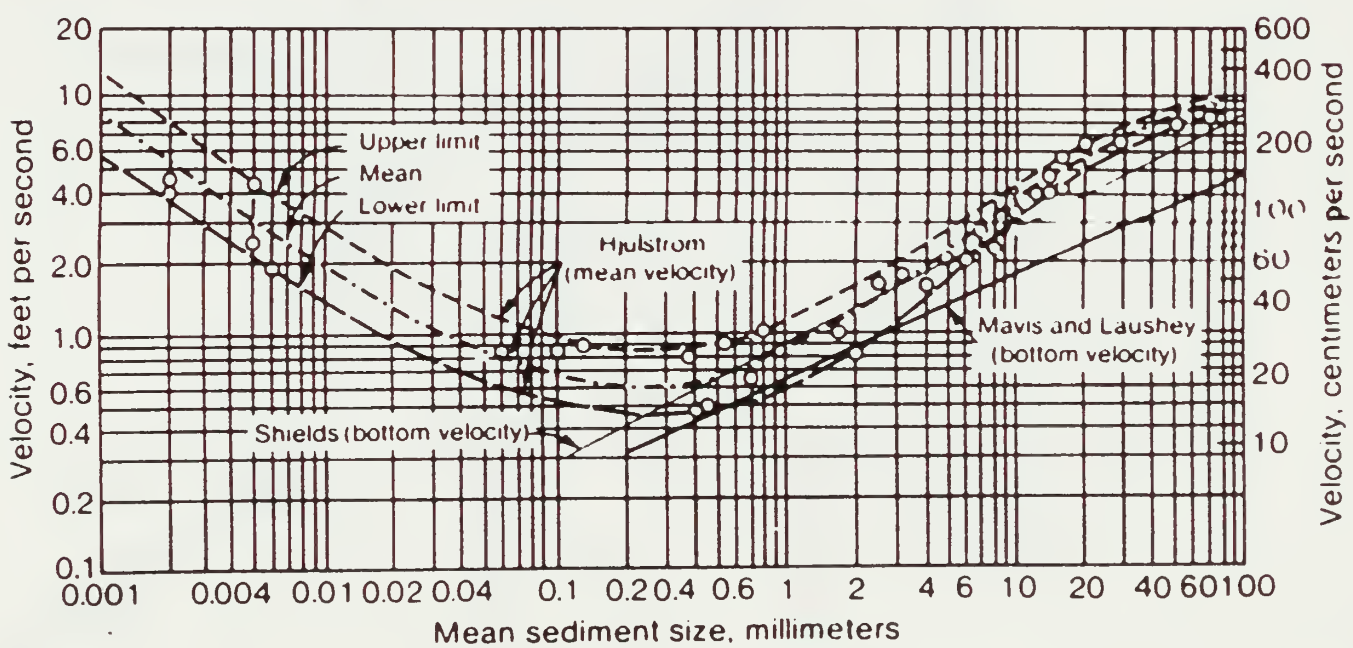


Figure 4. Critical water velocities for quartz sediment as function of mean grain size (after ASCE Task Committee, 1967).

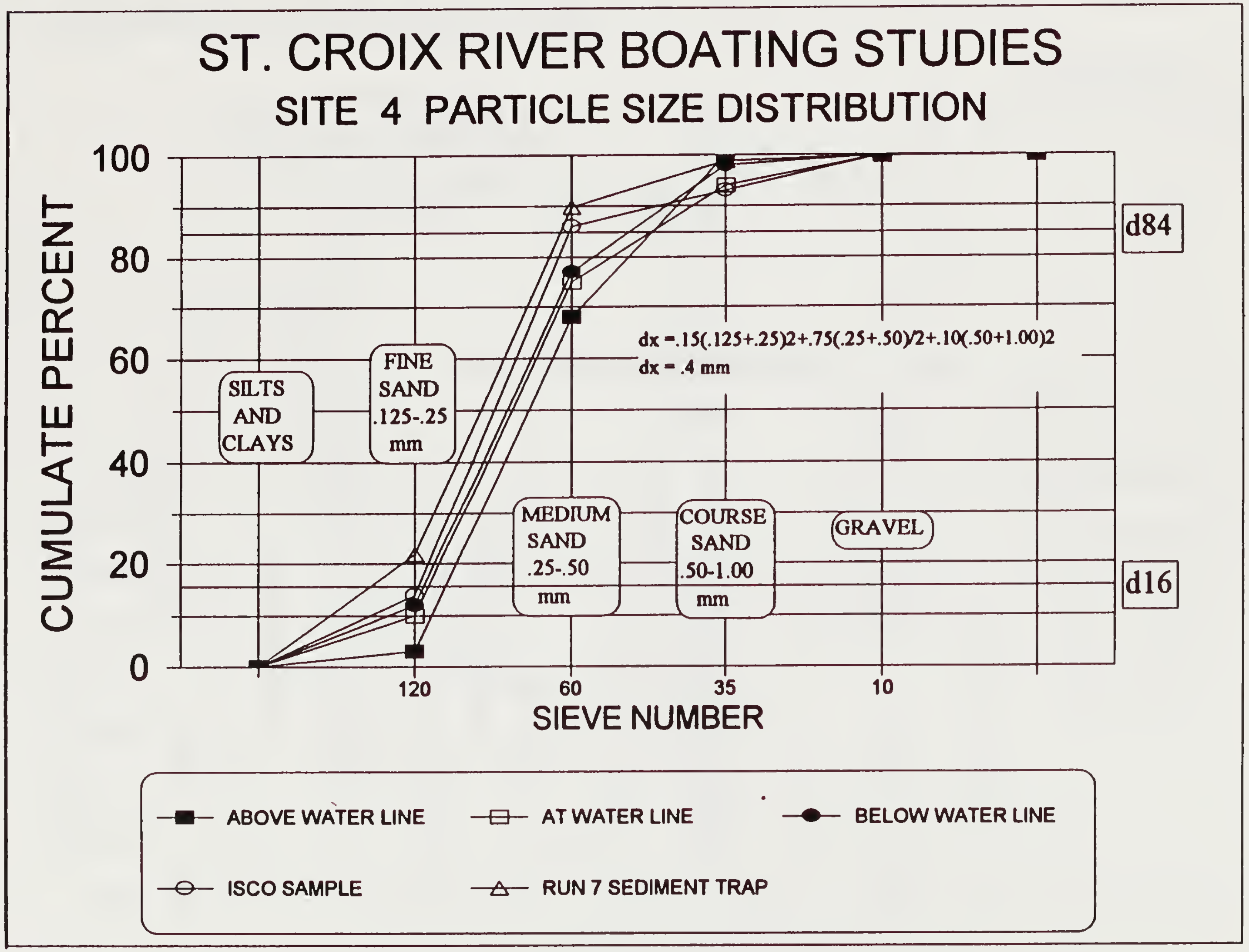


FIGURE 5. SEDIMENT PARTICLE SIZE DISTRIBUTION AT PIER ISLAND.

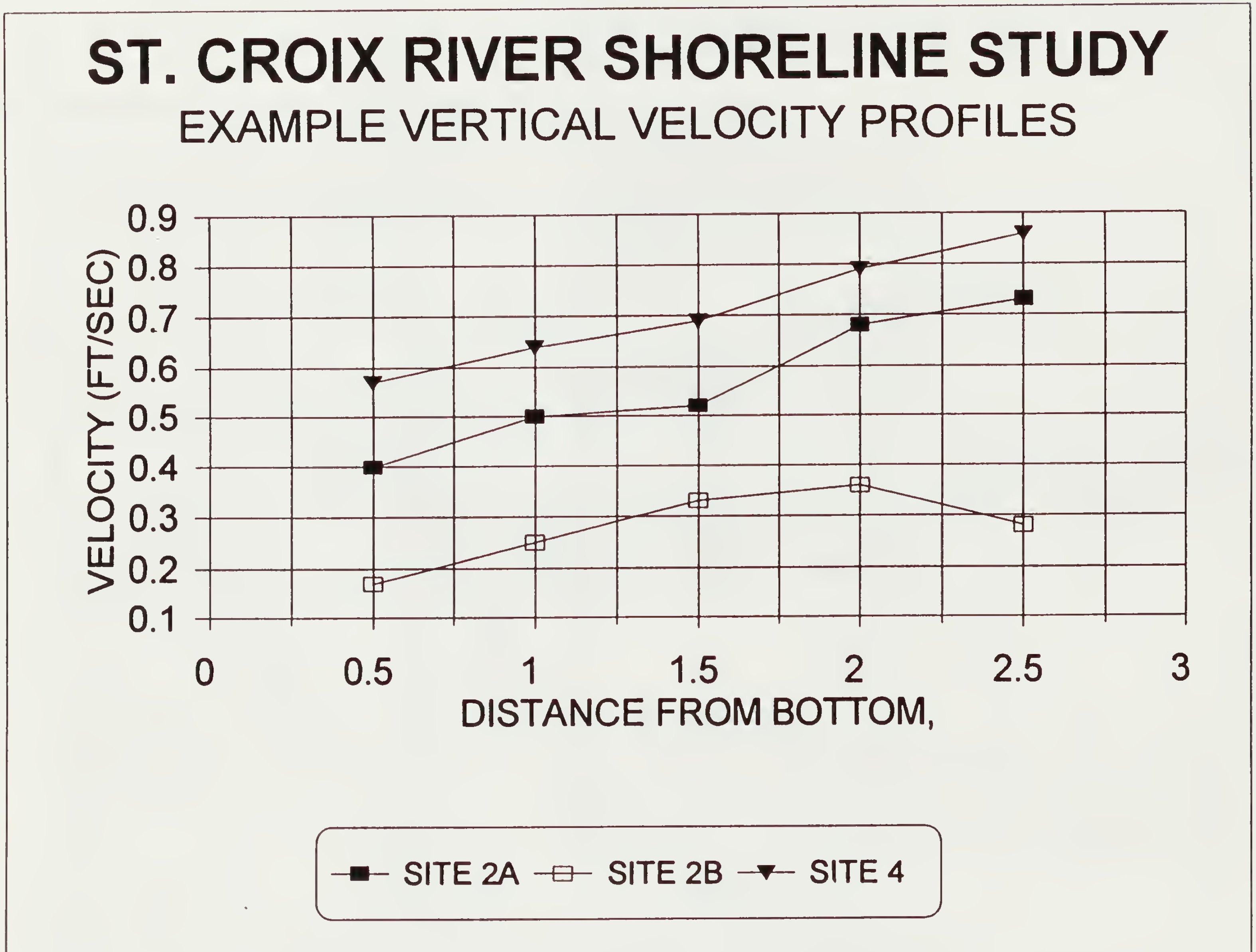


FIGURE 6. Example Vertical Flow Velocity Profiles.

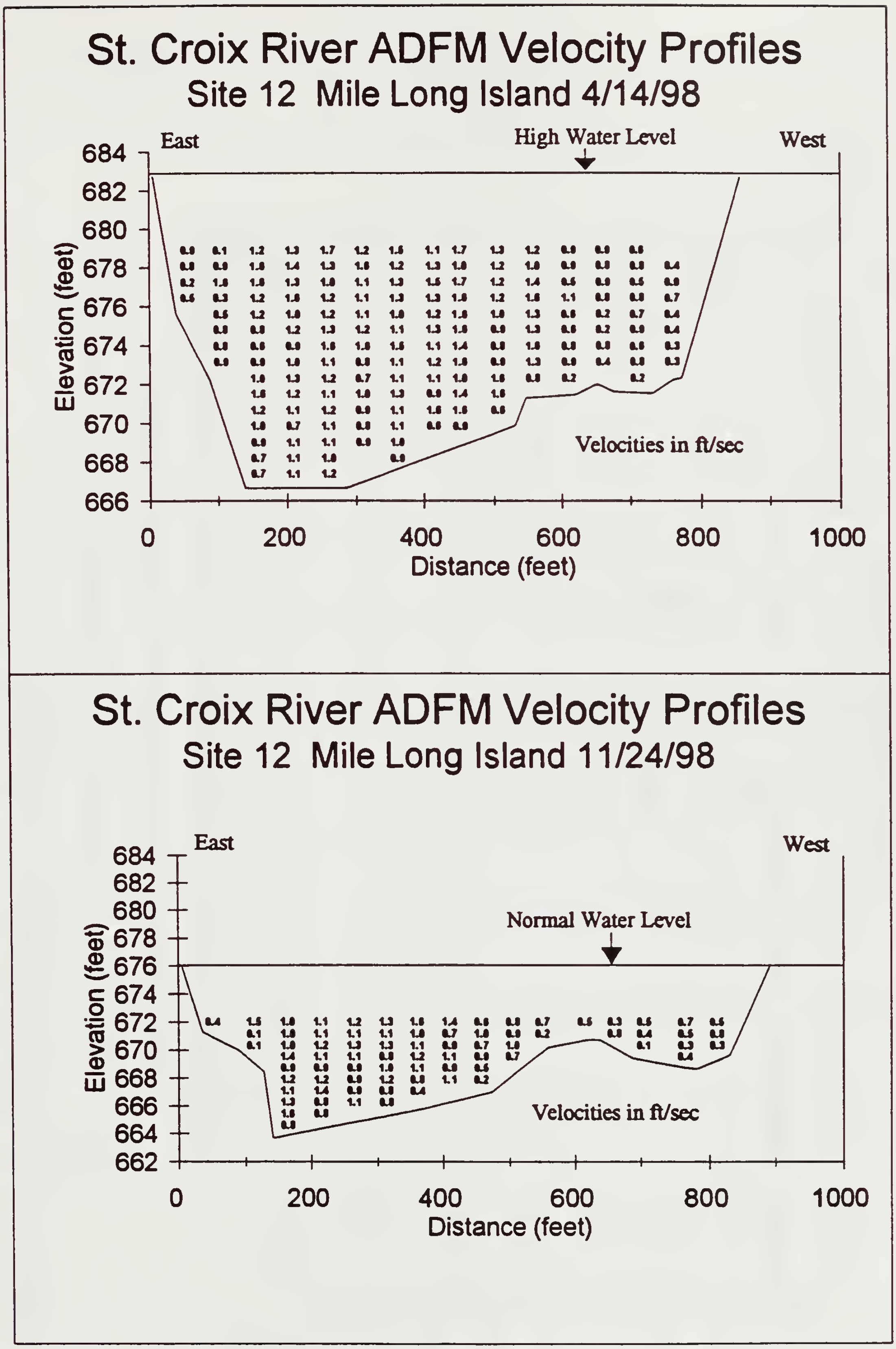


Figure 7. Acoustic Doppler Flow Meter Profile Example - Normal and Flood Velocities.

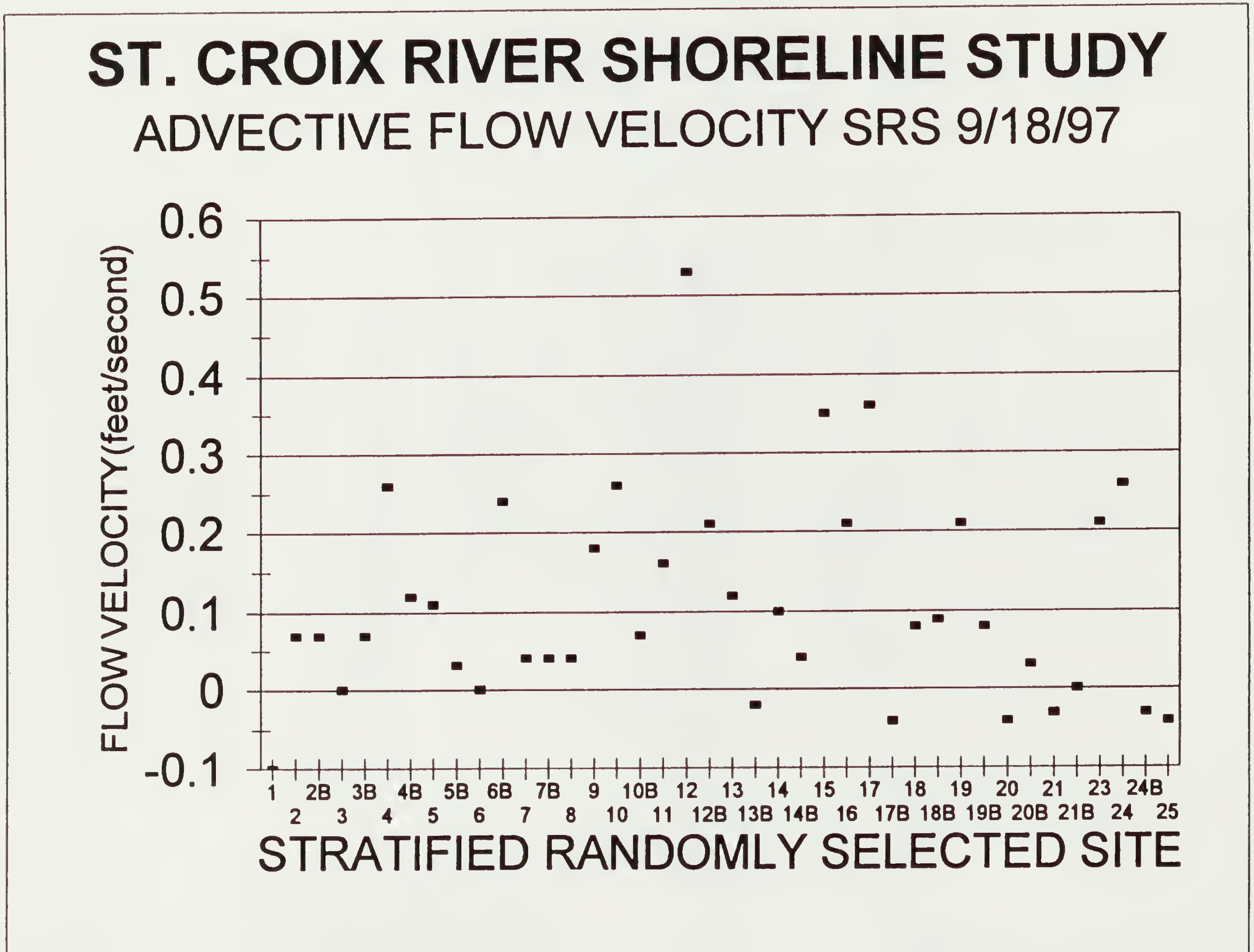


FIGURE 8. ADVECTIVE FLOW VELOCITIES AT SRS SITES.

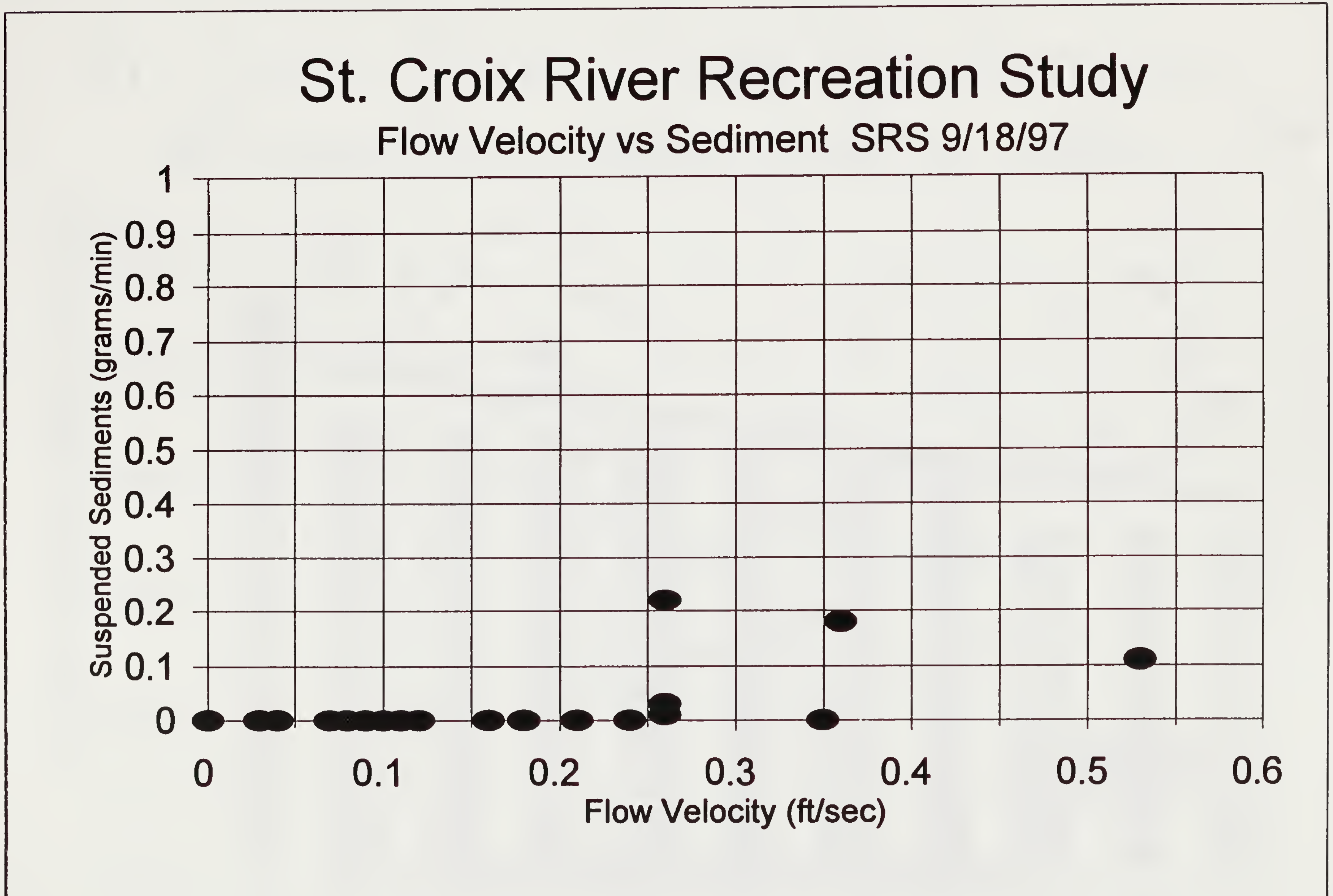


FIGURE 9. FLOW VELOCITY SEDIMENT TRAP RESULTS.

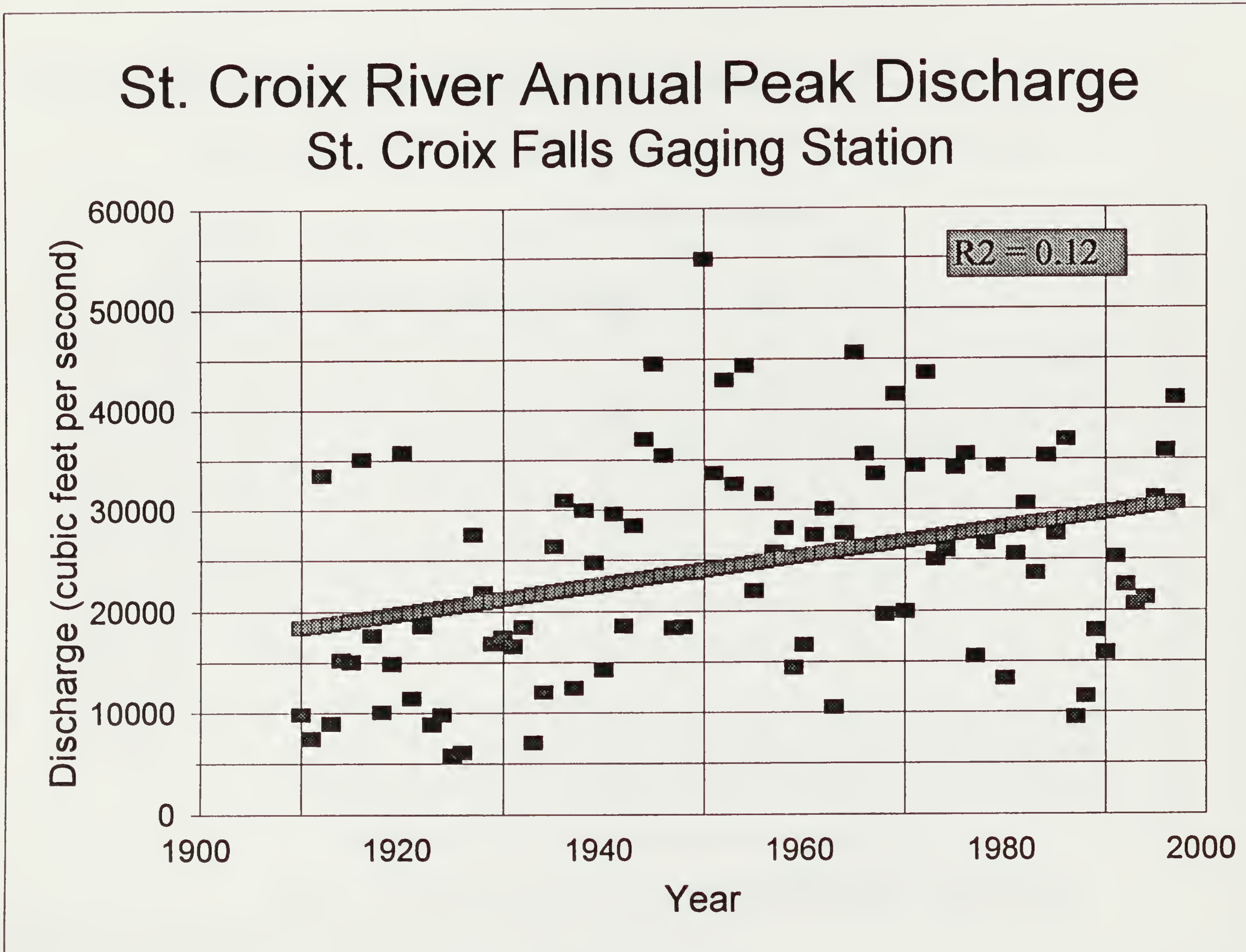


Figure 10. Flood Flow Trends 1910 - 1998.

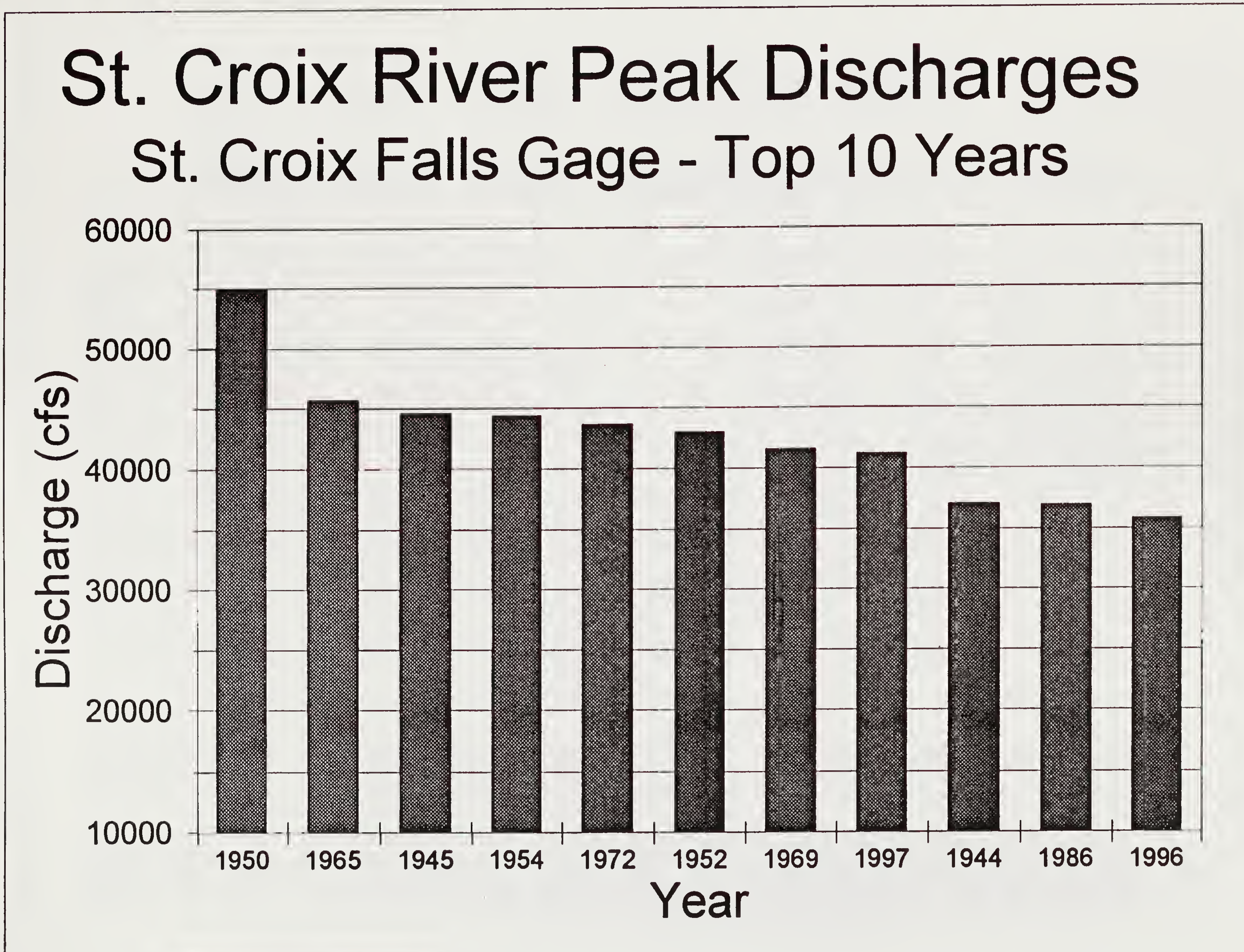


Figure 11. Ten Highest Flood Discharges Ranked in Descending Order.

		St. Croix River Bottom Velocity Profile Measurements										
		(All measurements were made 0.5 feet from bottom in feet per second.)										
WATER												
ELEVATION			Feet	from	water	line>	>>>	>>>	>>>	>>>	>>>	>>>
	Date	Site	2	4	6	8	10	12	14	16	18	20
676.32 WL	7/13/95	2A	0.13	0.19	0.28	0.37	0.44					
676.32 WL	7/13/95	2B	0.00	0.00	0.00	0.00	0.00	0.04	0.12	0.27		
676.32 WL	7/13/95	4	0.00	0.00	0.00	0.00	0.06	0.17	0.22	0.27	0.30	0.37
676.32 WL	7/13/95	9A	0.00	0.05	0.04	0.03	0.02					
676.32 WL	7/13/95	9B	0.00	0.19	0.22	0.26	0.27	0.24	0.27			
676.34 WL	6/29/95	11A	0.00	0.00	0.00	0.00	0.00	0.11	0.16	0.25		
676.34 WL	6/29/95	11B	0.00	0.00	0.00	0.00	0.02	0.17	0.41	0.41		
678.75 WL	10/26/95	2A	0.12	0.17	0.21	0.34	0.54	0.31				
678.75 WL	10/26/95	2B	0.00	0.00	0.00	0.04	0.01	0.07				
678.75 WL	10/26/95	7	0.38	0.37	0.31	0.34	0.39	0.35	0.32			
678.75 WL	10/26/95	10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
678.75 WL	10/26/95	9A	0.01	0.01	0.04							
678.75 WL	10/26/95	9B	0.04	0.07	0.22	0.26						
678.75 WL	10/26/95	4	0.00	0.00	0.00	0.00	0.00	.08	0.26	0.32	0.37	0.41
678.75 WL	10/26/95	11A	0.00	0.07	0.20	0.24	0.25	0.28	0.25			
678.75 WL	10/26/95	11B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
678.75 WL	10/26/95	12A	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
678.75 WL	10/26/95	12B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
675.30 WL	8/15/96	2A	0.33	0.45	0.23	0.60	0.20					
675.30 WL	8/15/96	2B	0.14	0.14	0.10	0.01						
675.30 WL	8/15/96	5	0.56	0.54	0.59	0.52	0.58	0.58				
675.30 WL	8/15/96	7	0.01	0.06								
675.30 WL	8/15/96	9A	0.02	0.02	0.08	0.05	0.08					
675.30 WL	8/15/96	9B	0.50	0.36	0.41	0.39	0.37					
675.30 WL	8/15/96	11A	0.02									
675.30 WL	8/15/96	11B	0.60	0.57	0.52	0.53	0.49					
675.45 WL	10/1/96	12A	0.07	0.08	0.04							
675.45 WL	10/1/96	12B	0.00									
675.36 WL	6/17/97	1A	0.10	0.05	0.01	-0.01	-0.01					
675.36 WL	6/17/97	1B	-0.02	-0.01	0.04	0.03	0.02	0.02	0.03	0.01		
676.03 WL	6/18/97	2A	0.18	0.08	0.26	0.37						
676.03 WL	6/18/97	2B	0.00	0.15	0.17							
676.03 WL	6/18/97	5	0.27	0.28	0.32	0.28	0.33	0.38	0.35	0.48		
676.03 WL	6/18/97	7	-0.01	-0.01	0.06							
676.03 WL	6/18/97	9A	-0.07	0.03	0.07	0.04	0.03	0.04	0.02	0.03		
676.03 WL	6/18/97	9B	0.21	0.26	0.29	0.36	0.30	0.32				
676.03 WL	6/18/97	10	0.15	0.15	0.10	0.08						
675.36 WL	6/17/97	11A	0.14									
675.36 WL	6/17/97	11B	0.39	0.41	0.48	0.48	0.45	0.43	0.52	0.43		
675.31 WL	10/9/97	1B	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.05
675.32 WL	10/10/97	2A	0.45	0.53	0.36	0.40						
675.32 WL	10/10/97	2B	0.04	0.02	0.01	0.03	0.02	0.09	0.07	0.07		
675.32 WL	10/10/97	4	0.04	0.07	0.01	0.09	0.20	0.34				
675.32 WL	10/10/97	5	0.25	0.28	0.29	0.36	0.36	0.33	0.46			
675.32 WL	10/10/97	7	0.09	0.07	0.10							
675.32 WL	10/10/97	9B	0.05	0.11	0.15	0.20	0.17	0.23	0.31			
675.32 WL	10/10/97	10	0.05	0.06	0.03	0.04	0.04					
675.31 WL	10/9/97	11B	0.20	0.28	0.27	0.32	0.36	0.34	0.38	0.45	0.38	
675.32 WL	10/10/97	12A	0.15	0.22	0.20	0.15	0.21	0.25	0.20	0.29		

Table 1. Bottom Velocity Profiles

ST. CROIX RIVER VERTICAL VELOCITY PROFILES (FEET PER SECOND)															
		HEIGHT													
WATER		FROM													
ELEVATION	DATE	RIVER	SITE	SITE	SITE	SITE	SITE	SITE	SITE	SITE	SITE	SITE	SITE	SITE	SITE
		BOTTOM	1B	2A	2B	4	5	7	9A	9B	10	11A	11B	12A	12B
678.75	10/26/95	0.50		0.40	0.17	0.57		0.27	0.04	0.39	0.31	0.30	0.43	0.03	0.26
678.75	10/26/95	1.00		0.50	0.25	0.64		0.18	0.10	0.43	0.29	0.43	0.51	0.02	0.36
678.75	10/26/95	1.50		0.52	0.33	0.69		0.22	0.11	0.39	0.31	0.39	0.68	0.06	0.42
678.75	10/26/95	2.00		0.68	0.36	0.79		0.10	0.09	0.36	0.36	0.41	0.80	0.07	0.55
678.75	10/26/95	2.50		0.73	0.28	0.86		0.23			0.29	0.44		0.08	
678.75	10/26/95	3.00						0.25			0.35				
			1B	2A	2B	4	5	7	9A	9B	10	11A	11B	12A	12B
680.25	5/31/96	0.50				0.42			0.20	0.48			0.25	0.43	0.30
680.25	5/31/96	1.00												0.46	0.35
680.25	5/31/96	1.60				0.52							0.64		
680.25	5/31/96	1.80							0.25	0.52		0.62			
680.25	5/31/96	1.50												0.48	0.28
680.25	5/31/96	2.00												0.71	0.47
680.25	5/31/96	2.50												0.78	0.43
680.25	5/31/96	3.00												0.55	0.48
680.25	5/31/96	3.50												0.72	0.43
680.25	5/31/96	4.00												0.69	0.46
680.25	5/31/96	4.50												0.70	0.51
680.25	5/31/96	5.00												0.71	0.48
680.25	5/31/96	5.50												0.72	0.39
680.25	5/31/96	6.00												0.71	0.45
680.25	5/31/96	6.40				0.64							0.83		
680.25	5/31/96	6.50												0.82	0.55
680.25	5/31/96	7.20							0.29	0.84		0.77			
680.25	5/31/96	7.00												0.72	0.61
680.25	5/31/96	7.50												0.72	0.55
680.25	5/31/96	8.00												0.70	0.65
680.25	5/31/96	8.50													
			1B	2A	2B	4	5	7	9A	9B	10	11A	11B	12A	12B
675.30	8/15/96	0.50		0.37	0.22		0.47	0.11	0.01	0.48	0.01	0.31	0.57	0.04	0.00
675.30	8/15/96	1.00		0.69	0.28		0.57	0.16	0.01	0.60	0.08	0.35	0.71	0.07	0.00
675.30	8/15/96	1.50		0.70	0.31		0.69	0.17	0.00	0.63	0.10			0.05	0.00
675.30	8/15/96	2.00		0.82	0.33		0.57	0.21		0.63	0.13				0.00
675.30	8/15/96	2.50		0.90	0.33		0.53	0.11		0.60	0.18				
675.30	8/15/96	3.00		0.90			0.50	0.11							
			1B	2A	2B	4	5	7	9A	9B	10	11A	11B	12A	12B
675.65	6/18/97	0.50		0.37	0.17		0.48	0.06	0.03	0.32	0.08	0.14	0.43	0.18	
675.65	6/18/97	1.00		0.52	0.17		0.49	0.11	0.04	0.37	0.2	0.18	0.43	0.17	
675.65	6/18/97	1.50			0.23		0.52	0.15	0.05	0.41	0.2	0.18	0.55	0.27	
675.65	6/18/97	2.00			0.2		0.49	0.18	0.03	0.40	0.26	0.14	0.58	0.29	
675.65	6/18/97	2.50			0.28		0.49	0.15	0.02	0.40			0.67	0.31	
675.65	6/18/97	3.00					0.51	0.23						0.31	
			1B	2A	2B	4	5.00	7	9A	9B	10	11A	11B	12A	12B
675.31	10/9/97	0.50	0.13	0.40	0.07	0.34	0.46	0.10		0.31	0.04		0.38	0.29	
675.31	10/9/97	1.00	0.11	0.42	0.10	0.35	0.46	0.03		0.40	0.01		0.50	0.27	
675.31	10/9/97	1.50	0.10	0.42	0.10	0.35	0.48	0.24		0.40	0.02		0.58	0.36	
675.31	10/9/97	2.00	0.13	0.42	0.11	0.45		0.16		0.45				0.38	
675.31	10/9/97	2.50	0.10		0.12	0.49		0.04		0.43				0.3	
675.31	10/9/97	3.00												0.45	

Table 2. Vertical Velocity Profiles

ACOUSTIC DOPPLER FLOW METER - METROPOLITAN COUNCIL ENVIRONMENTAL SERVICES TRANSECTS COLLECTED ON APRIL 13, 1998 AND NOVEMBER 24, 1998.

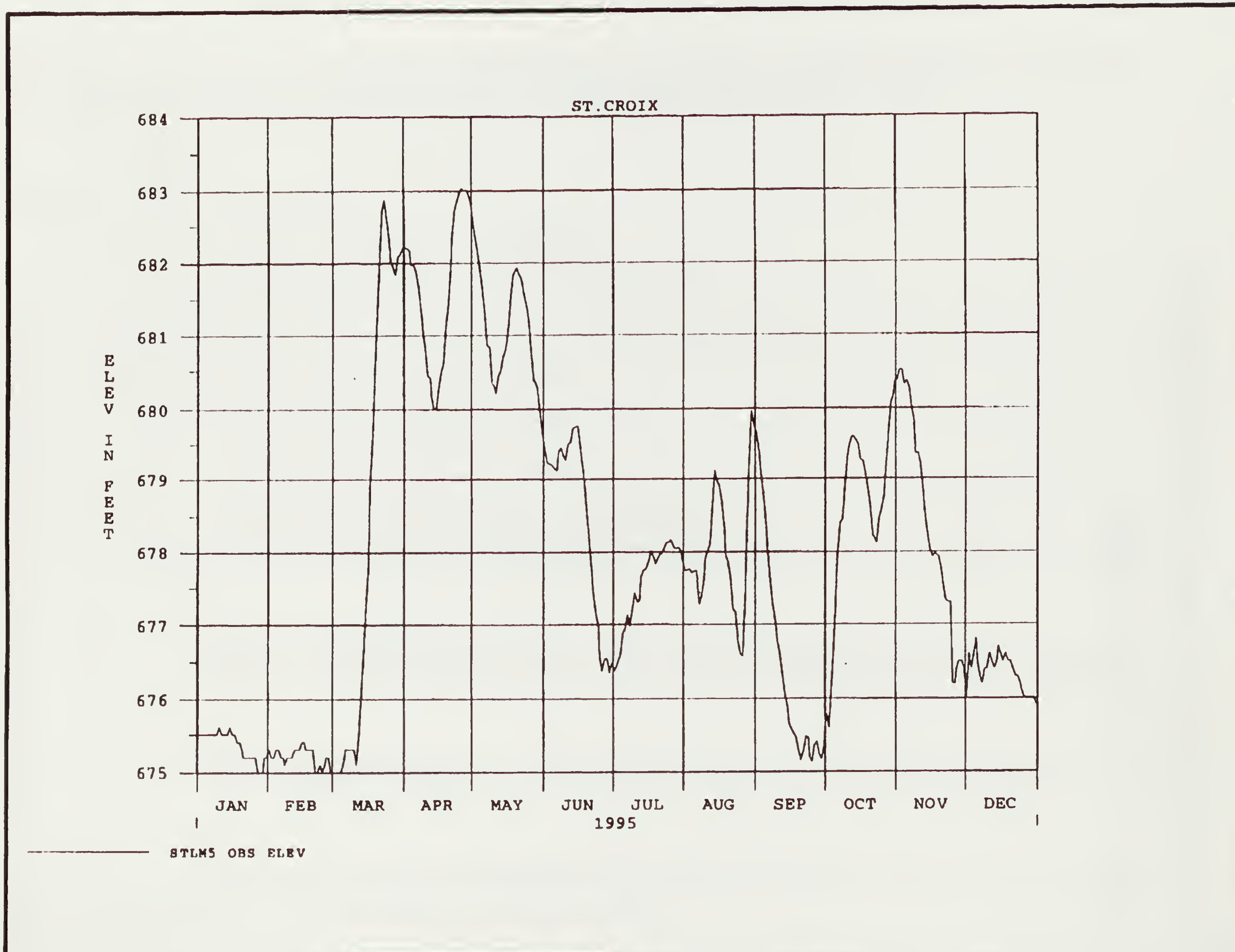
TRANSECT	FIXED SURVEY SITES	DESCRIPTION
1	12A and 12B	East to West Upstream of Mile Long Island.
2	1A and 1B	West to East Downstream of Island near Lyman's Slough.
3	9A and 9B	East to West Downstream and Across Lower Tip of Scout Camp Island.
4	11A and 11B	West to East Upstream of Schwartz Island.
5	4 and 5	East to West between Islands near Pillars.
6	10	West to East Upstream of Beer Can Island.
7	10	Between Island and Wisconsin Shore - November Only.
8	7 and 2B	East to West on Upstream Side of Picnic Island.

Table 3. Acoustic Doppler Flow Meter Transect Location Descriptions.

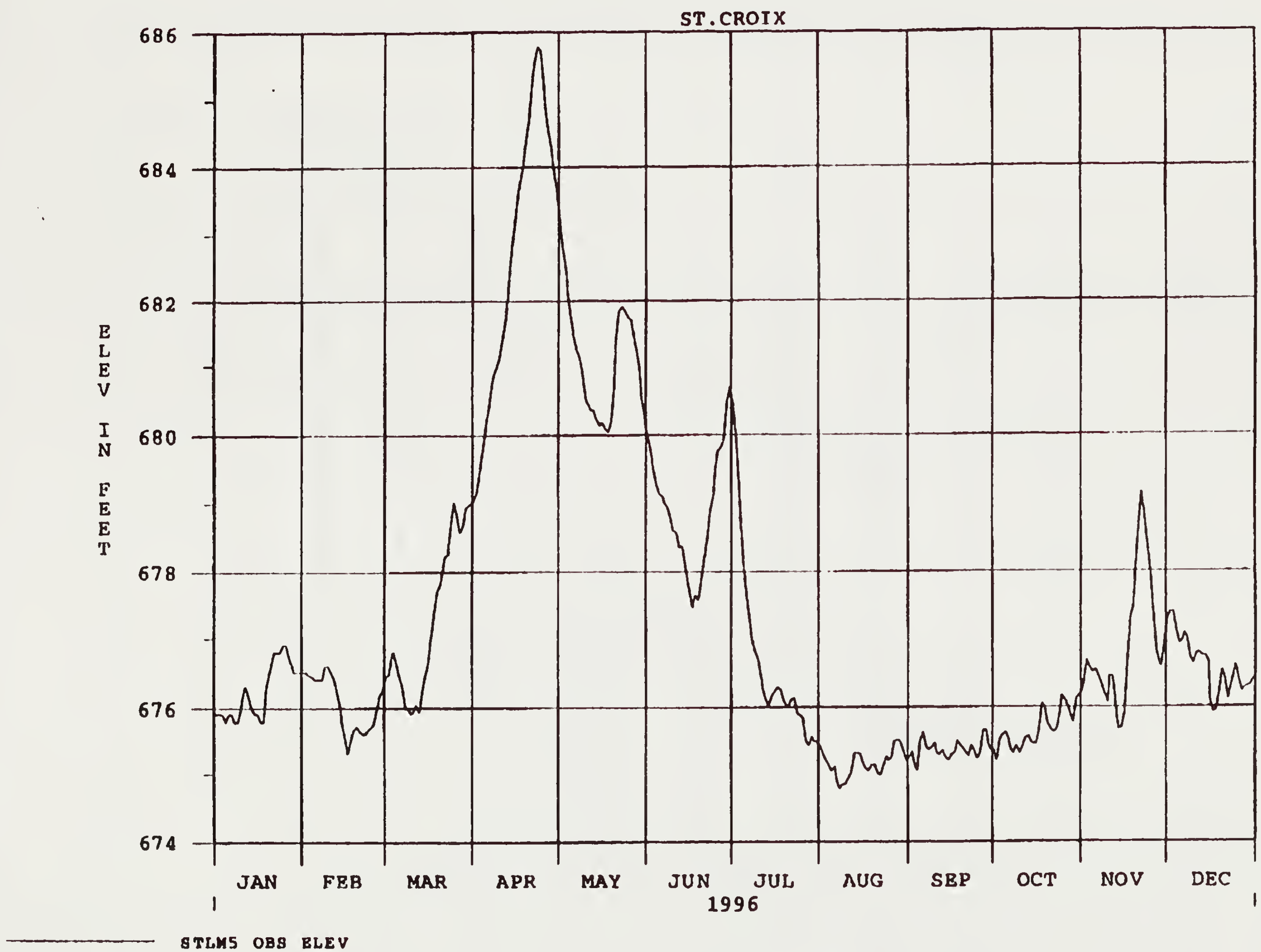
ST. CROIX RIVER FLOW VELOCITY/SEDIMENT TRAP RESULTS

SITE NUMBER	LOCATION	FLOW VEL FT/SEC	SEDIMENT (GRAMS)
1	1	-0.1	0
2	2	0.07	0
3	2B	0.07	0
4	3	0	0
5	3B	0.07	0
6	4	0.26	0.03
7	4B	0.12	0
8	5	0.11	0
9	5B	0.03	0
10	6	0	0
11	6B	0.24	0
12	7	0.04	0
13	7B	0.04	0
14	8	0.04	0
15	9	0.18	0
16	10	0.26	0.01
17	10B	0.07	0
18	11	0.16	0
19	12	0.53	0.11
20	12B	0.21	0
21	13	0.12	0
22	13B	-0.02	0
23	14	0.1	0
24	14B	0.04	0
25	15	0.35	0
26	16	0.21	0
27	17	0.36	0.18
28	17B	-0.04	0
29	18	0.08	0
30	18B	0.09	0
31	19	0.21	0
32	19B	0.08	0
33	20	-0.04	0
34	20B	0.03	0
35	21	-0.03	0
36	21B	0	0
37	23	0.21	0
38	24	0.26	0.22
39	24B	-0.03	0
40	25	-0.04	0

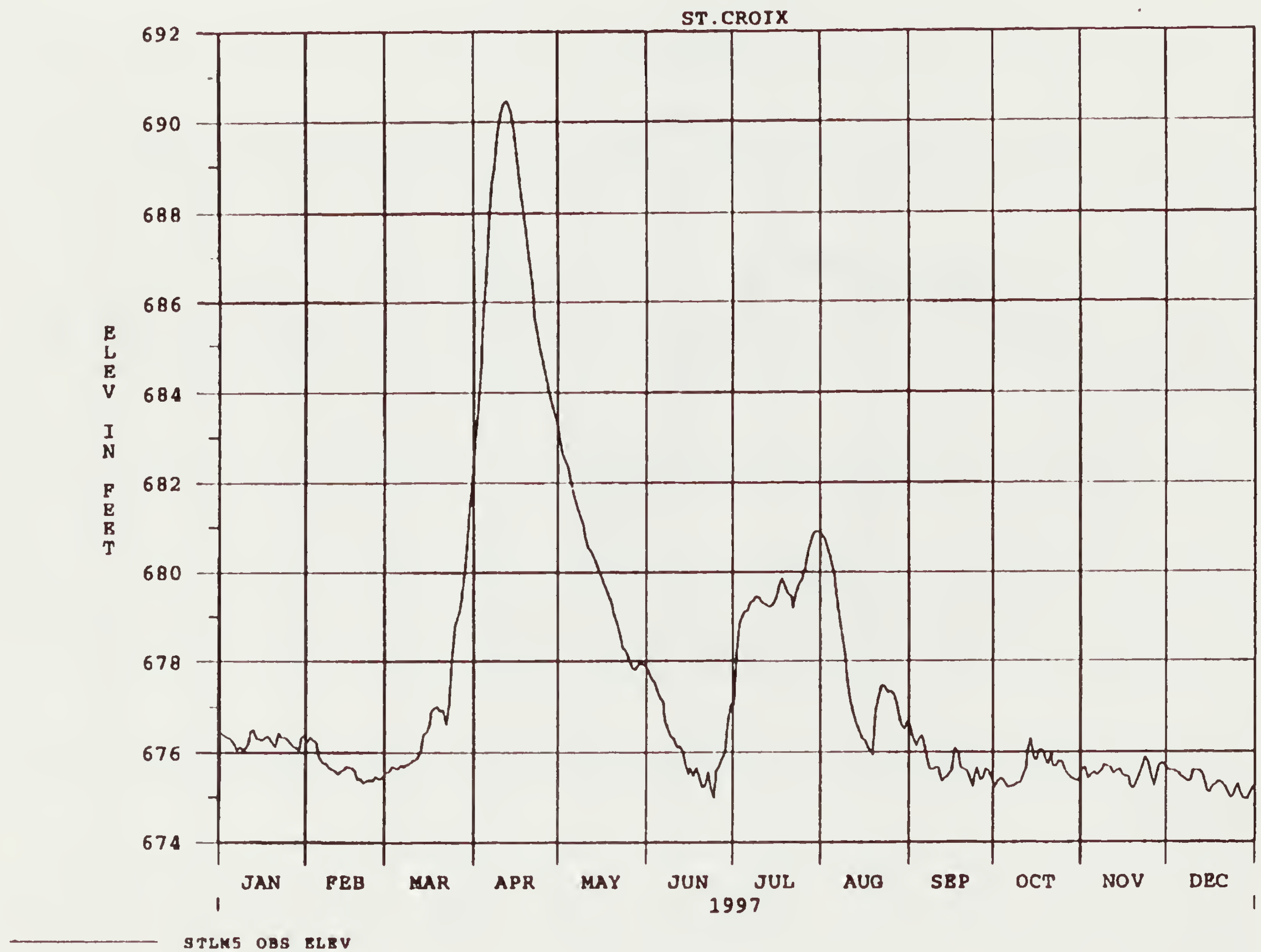
TABLE 4. SRS SITE MEASURED SEDIMENT TRAP VALUES.



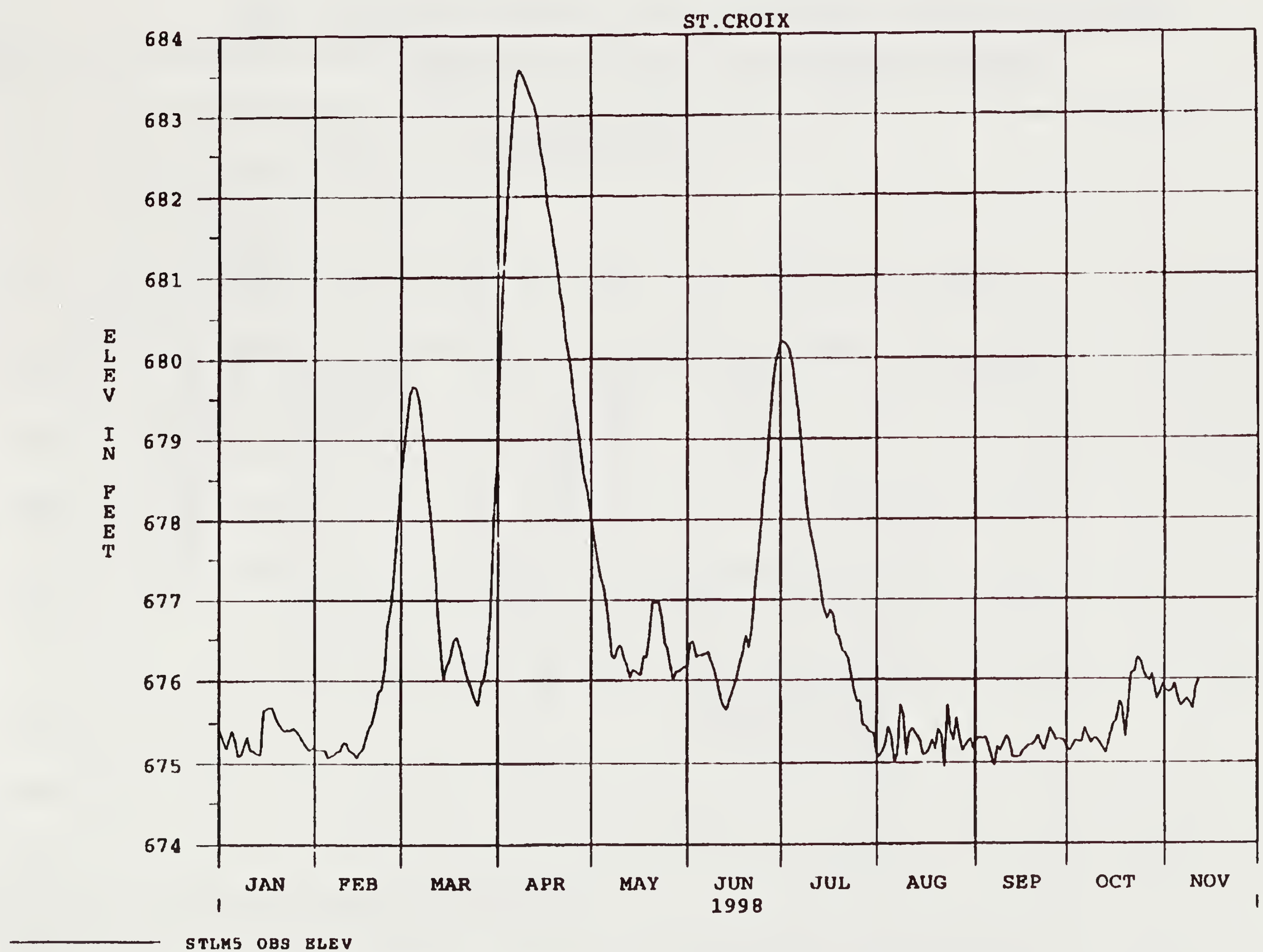
Appendix 1. Stage Hydrographs for the Stillwater Gage 1995 - 1998.



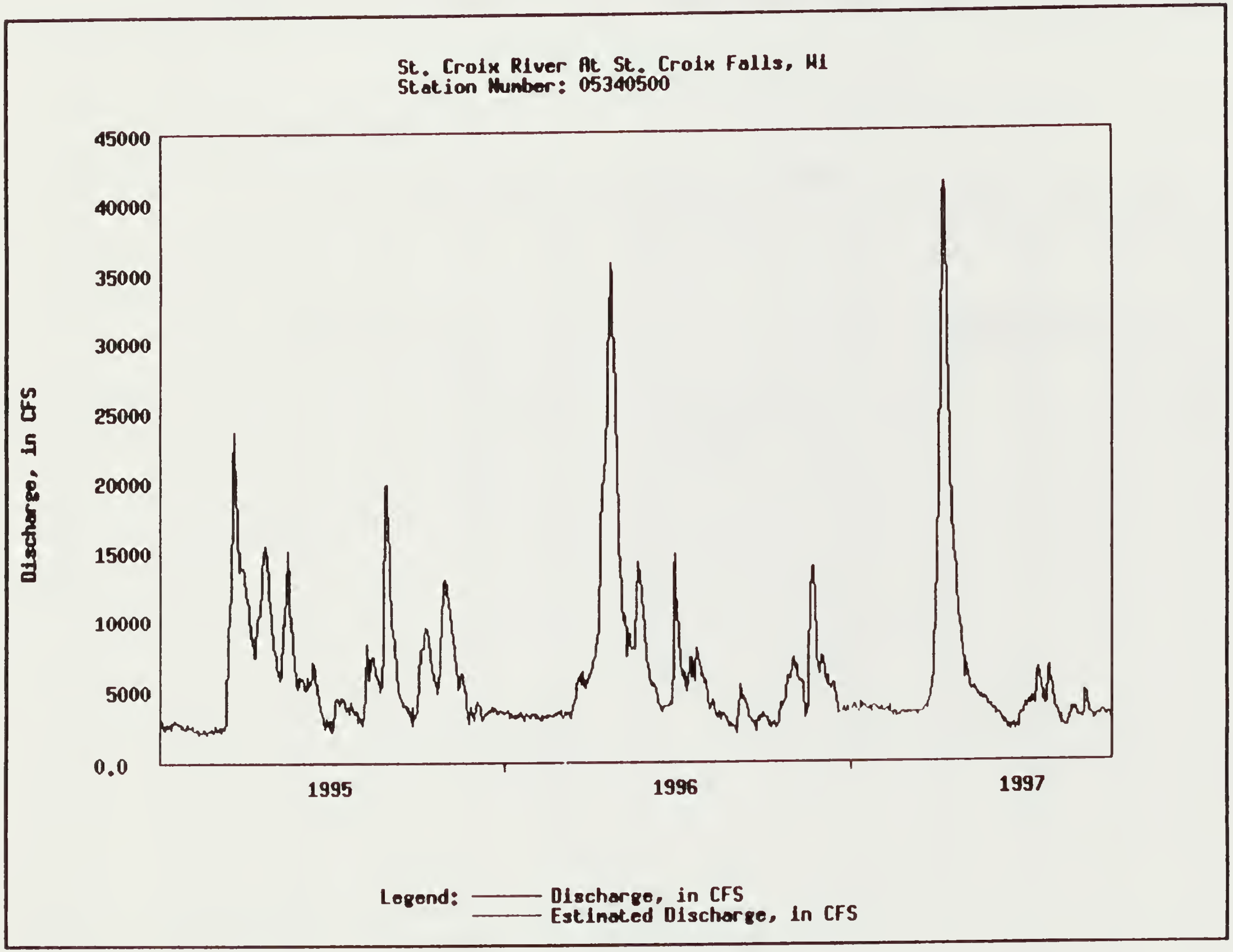
ST.CROIX
ELEV IN FEET
686
684
682
680
678
676
674
JAN FEB MAR APR MAY JUN JUL AUG SEP OCT NOV DEC
1996
STLM5 OBS ELEV



ST.CROIX
692
690
688
686
684
682
680
678
676
674
ELEV IN FEET
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
DEC
1997
STLM5 OBS ELEV

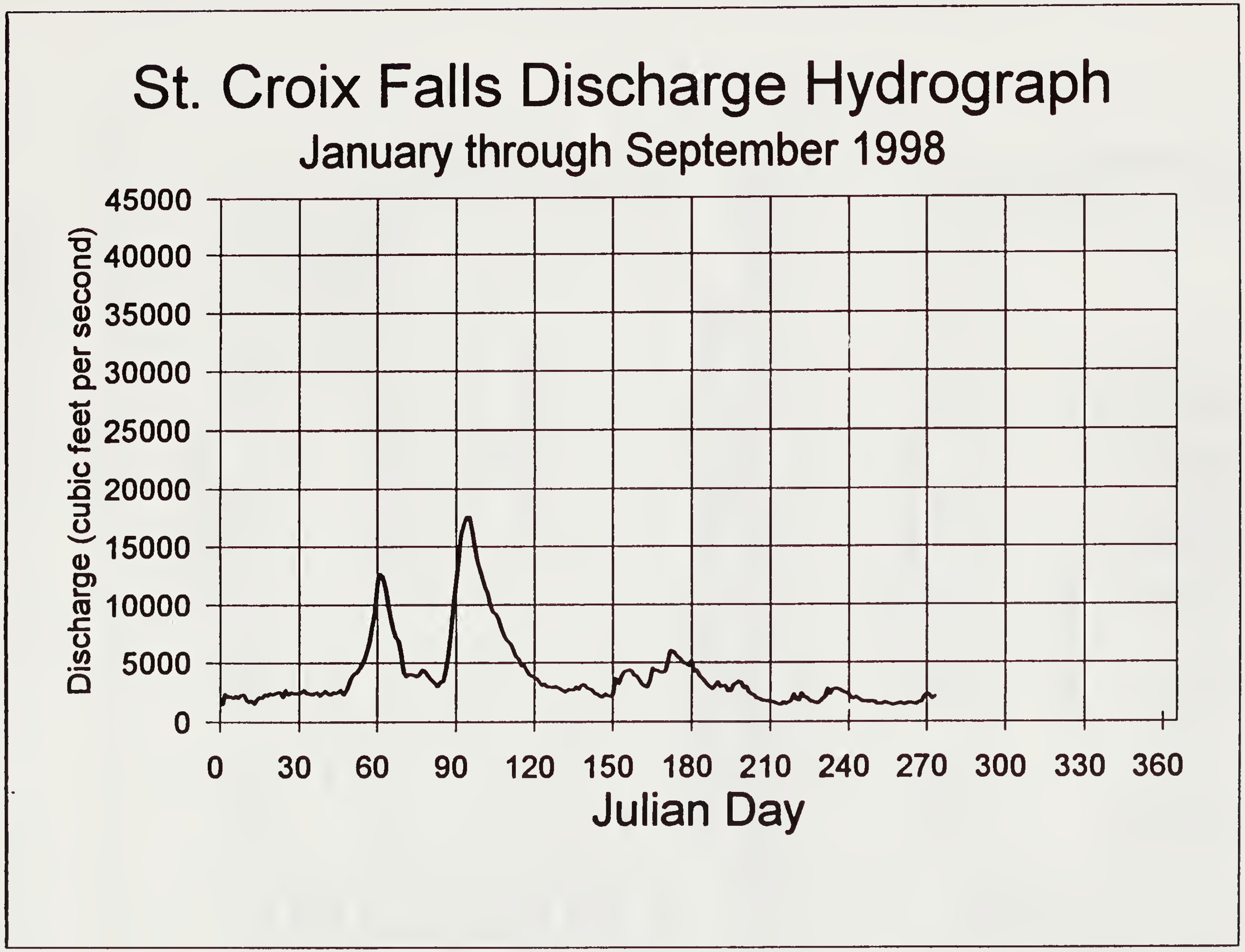


ST.CROIX
684
683
682
681
680
679
678
677
676
675
674
ELEV IN FEET
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV
1998
STLM5 OBS ELEV

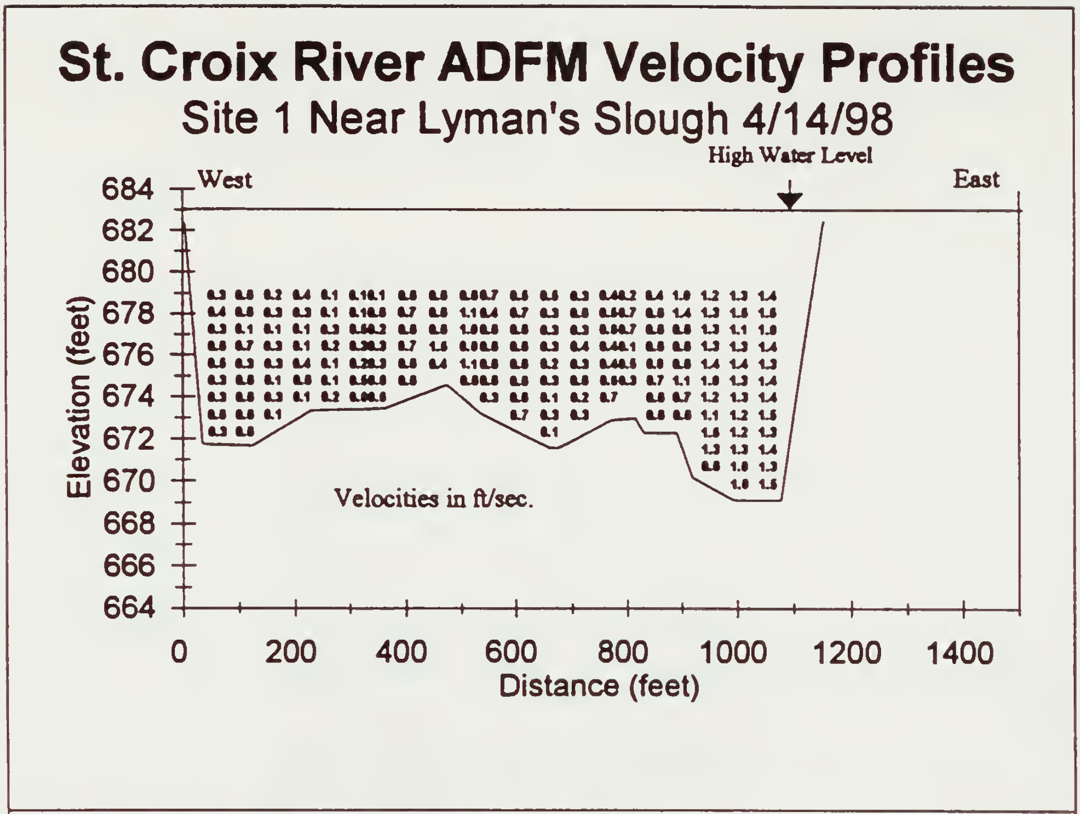


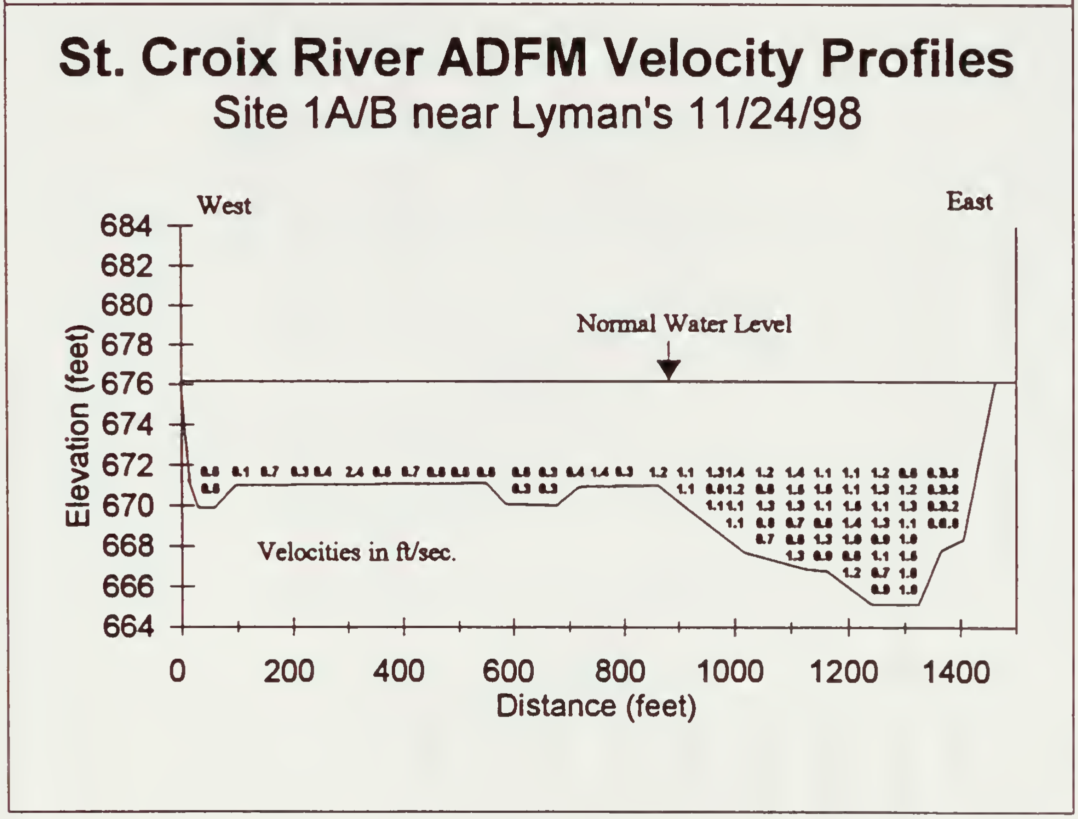
Some stations have red data points. These represent days for which data were estimated, rather than recorded.

Appendix 2. Discharge Hydrographs for the St. Croix Falls Gage 1995 - 1998.



Appendix 2. St. Croix Falls Discharge Hydrograph.

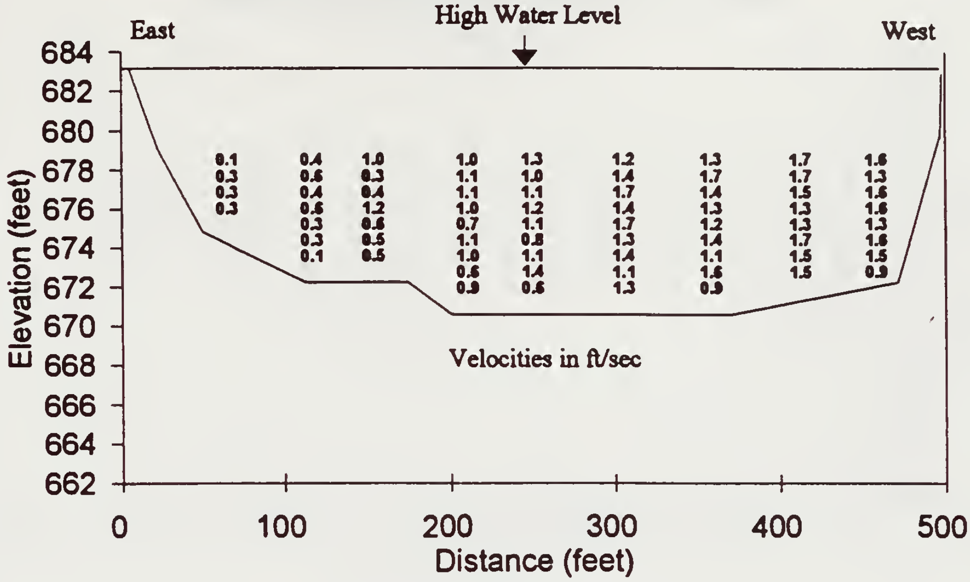




Appendix 3. Acoustic Doppler Flow Meter - Fixed Sites Normal and Flood Velocities

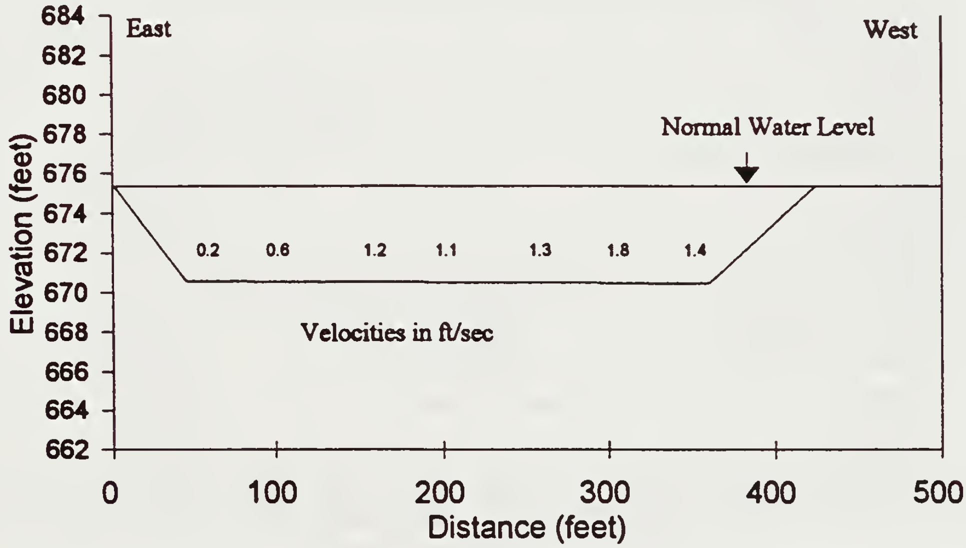
St. Croix River ADFM Velocity Profiles

Sites 4&5 Pillar Island 4/14/98



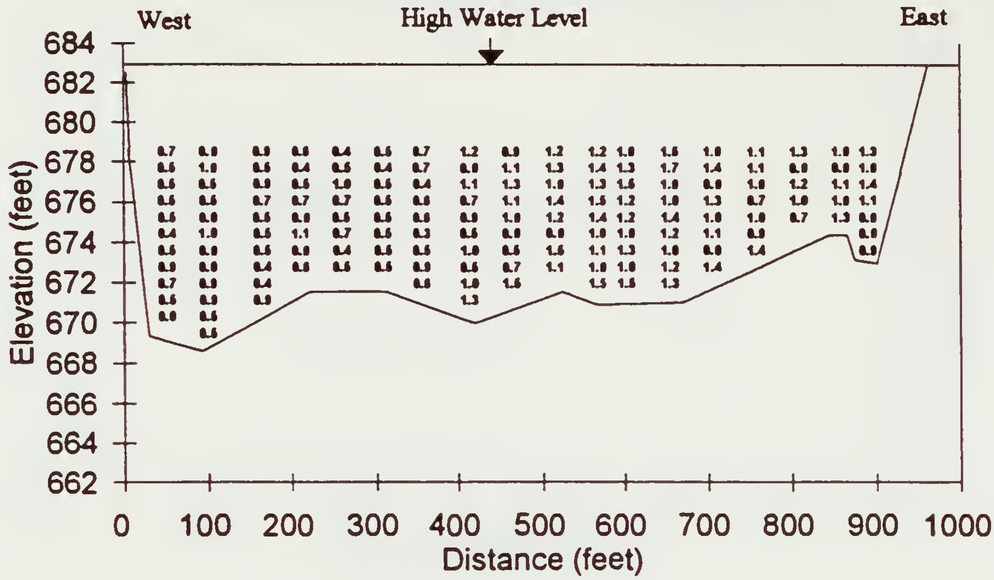
St. Croix River ADFM Velocity Profiles

Sites 4&5 Pillar Island 11/24/98



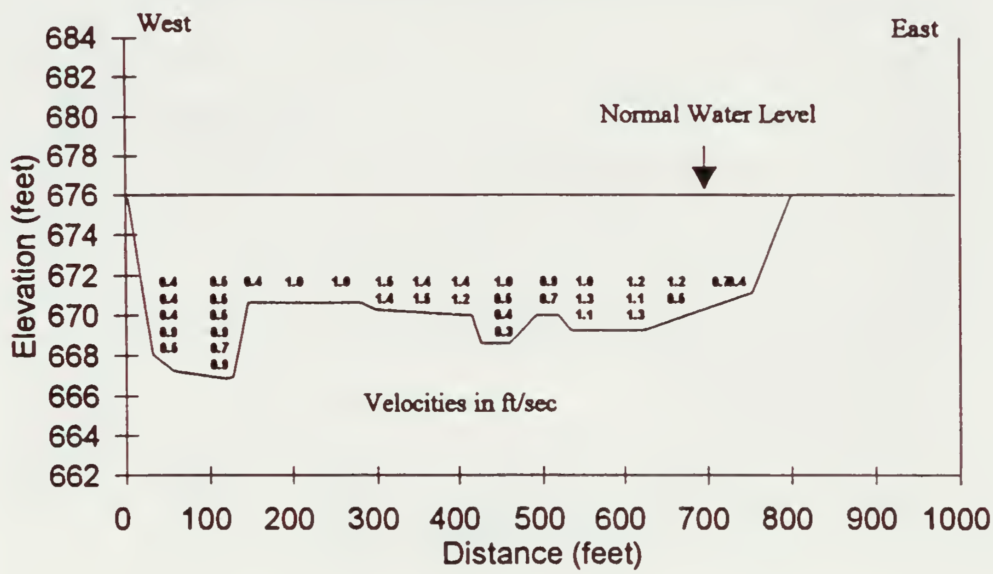
St. Croix River ADFM Velocity Profiles

Site 11 Schwartz Island 4/14/98

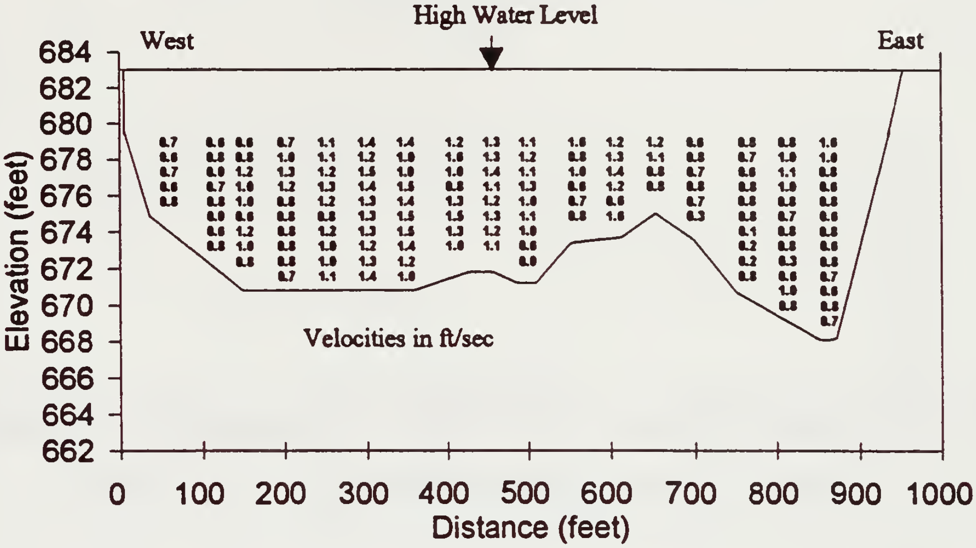


St. Croix River ADFM Velocity Profiles

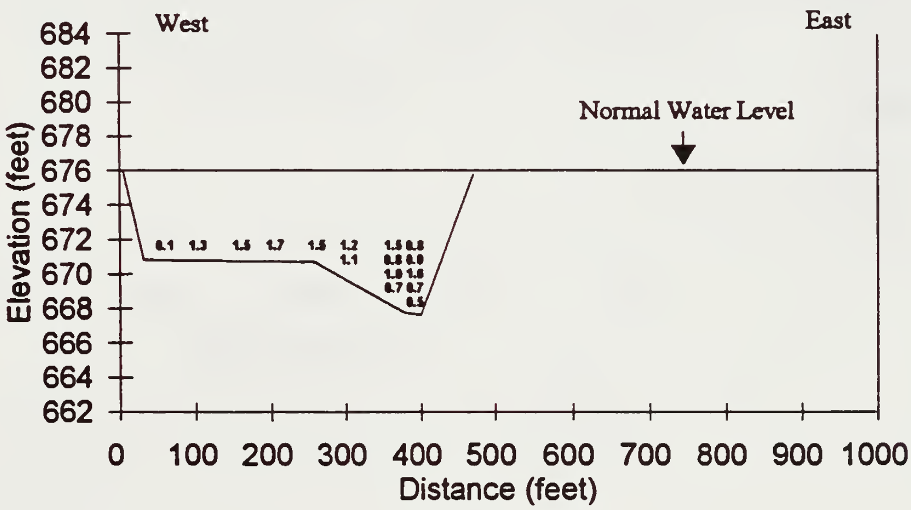
Site 11 Schwartz Island 11/24/98

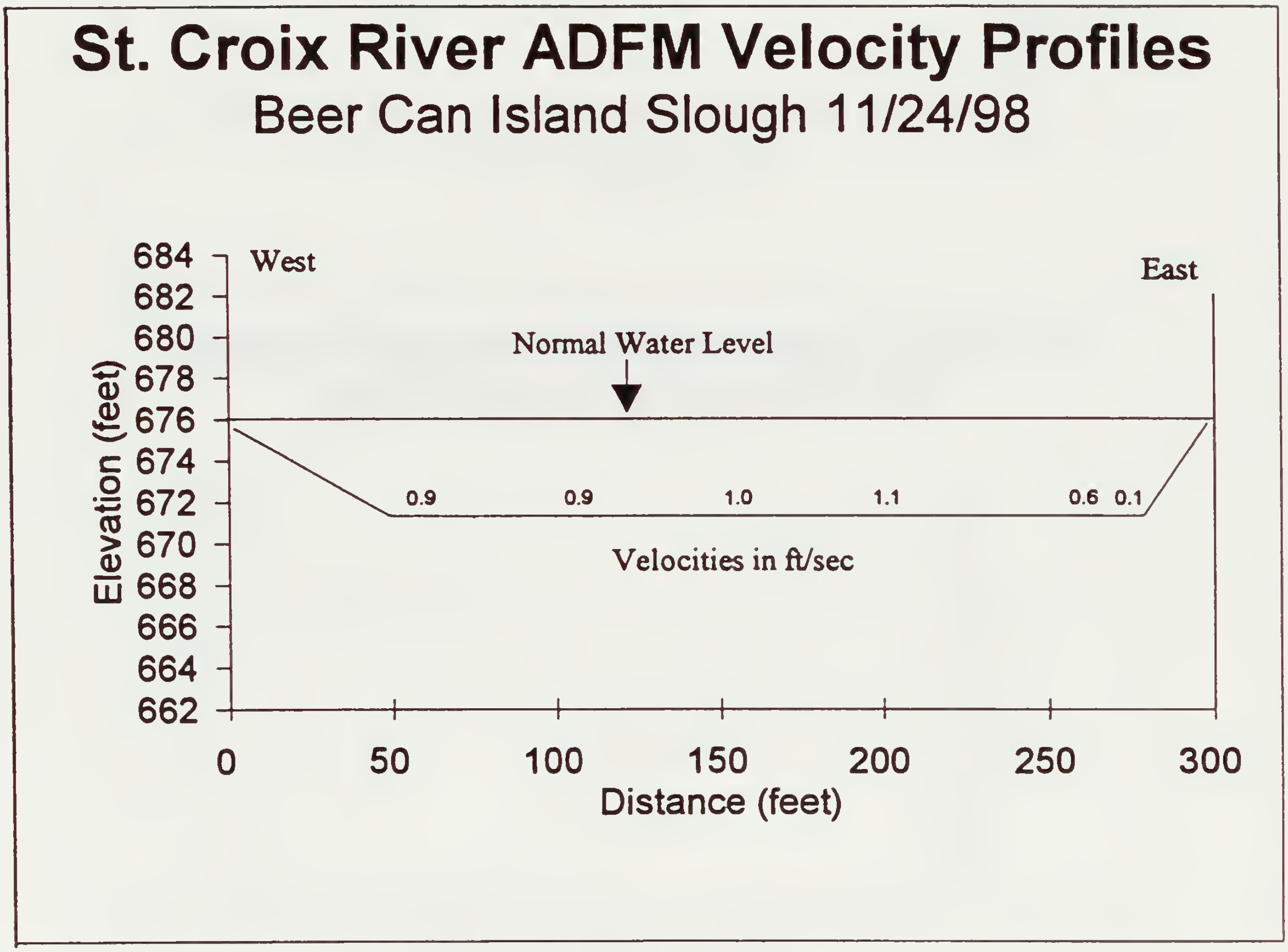


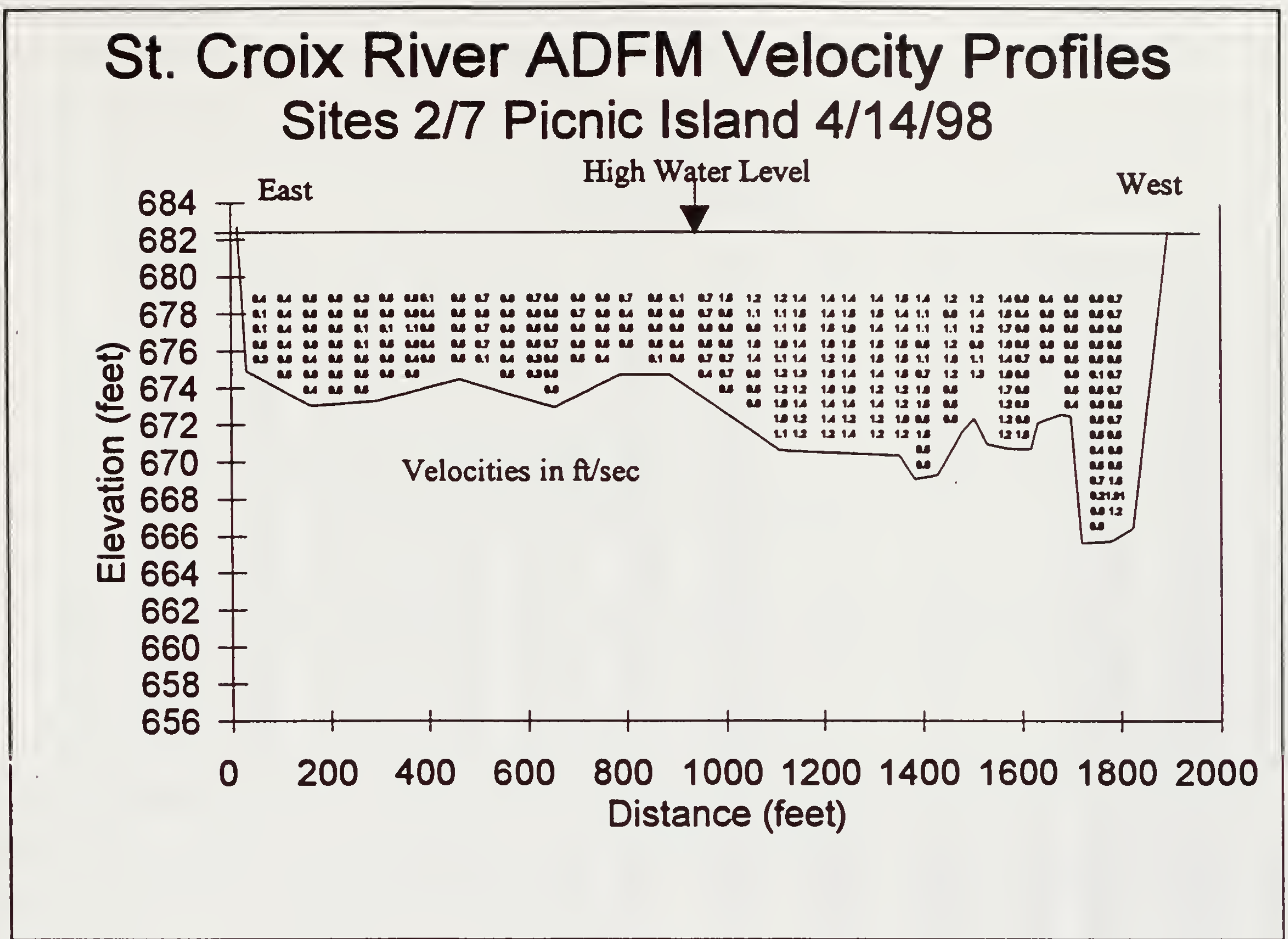
St Croix River ADFM Velocity Profiles
Site 10 Beer Can Island 4/14/98

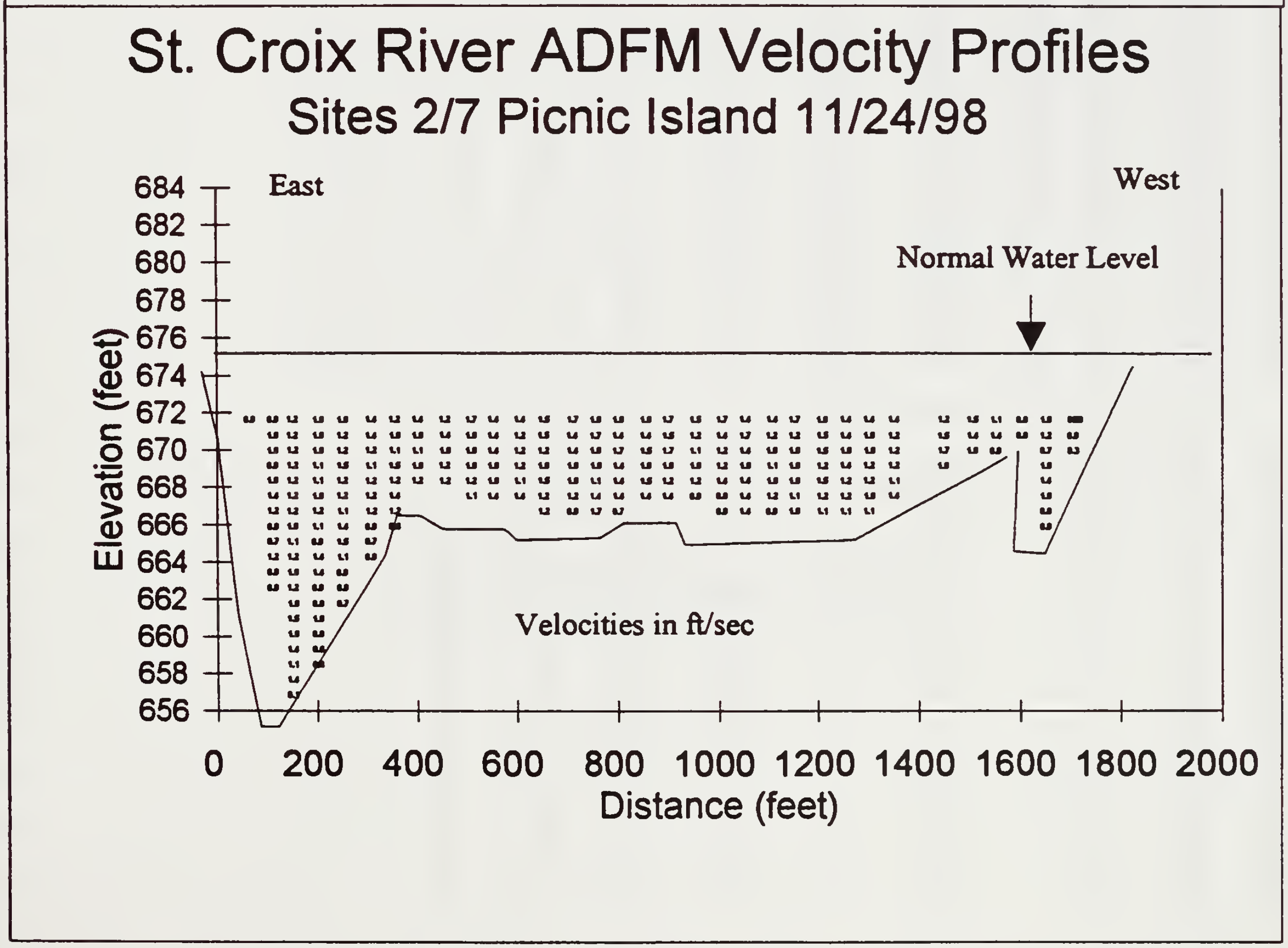


St. Croix River ADFM Velocity Profiles
Site 10 Beer Can Island 11/24/98




St. Croix River ADFM Velocity Profiles
Beer Can Island Slough 11/24/98
West
East
Normal Water Level
0.9
0.9
1.0
1.1
0.6
0.1
Velocities in ft/sec
Elevation (feet)
684
682
680
678
676
674
672
670
668
666
664
662
0
50
100
150
200
250
300
Distance (feet)


St. Croix River ADFM Velocity Profiles
Sites 2/7 Picnic Island 4/14/98
High Water Level
East
West
Elevation (feet)
684
682
680
678
676
674
672
670
668
666
664
662
660
658
656
Velocities in ft/sec
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Distance (feet)


St. Croix River ADFM Velocity Profiles
Sites 2/7 Picnic Island 11/24/98
East
West
Normal Water Level
Elevation (feet)
684
682
680
678
676
674
672
670
668
666
664
662
660
658
656
Velocities in ft/sec
0
200
400
600
800
1000
1200
1400
1600
1800
2000
Distance (feet)

IHA Annual Summary statistics
Stillwater Gage Trend Analysis

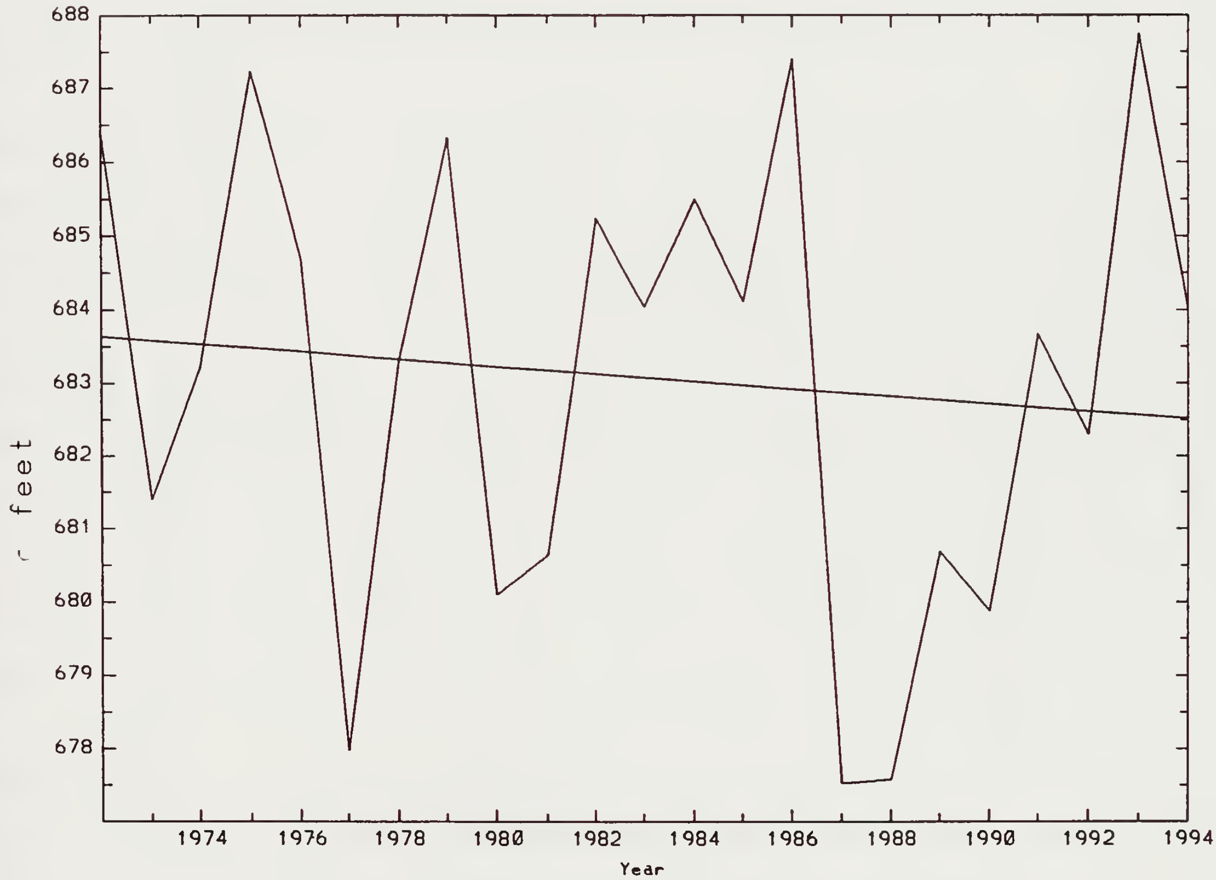
Year	October	November	Decembe	January	February	March	April	May	June	July	August	September
1972	675.72	677.04	0	0	0	682.68	681.48	680.75	678.35	678.03	679.8	676.45
1973	677.78	676.28	0	0	0	681.63	678.63	678.35	676.84	675.36	675.43	675.37
1974	675.34	675.46	0	0	0	675.6	679.44	679.34	679.96	675.48	675.36	675.27
1975	675.32	675.5	0	0	0	675.1	679.67	682.52	678.96	679.28	675.35	675.31
1976	675.33	675.29	0	0	0	681.84	680.24	675.38	675.46	675.39	675.42	675.35
1977	676.71	676.28	0	0	0	675.59	675.52	675.32	675.46	675.37	675.34	676.18
1978	675.51	675.37	0	0	0	678.96	681.48	677.44	677.52	679.29	676.35	676.8
1979	675.5	676.96	0	0	0	678.93	683.82	682.61	678.65	678.24	677	677.04
1980	675.42	675.41	0	0	0	677.3	678.39	675.48	676.7	675.38	675.49	675.67
1981	676.73	675.93	0	0	0	675.69	676.4	676.66	677.49	676.75	675.98	675.83
1982	677.98	677.54	0	0	0	679.28	683.33	680.96	677.35	676.07	675.5	675.58
1983	676.24	676.17	0	0	0	678.95	682.44	679.43	677.45	679.65	675.63	675.61
1984	677.92	677.81	0	0	0	680.16	682.58	681.75	682.28	679.47	675.66	675.55
1985	680.06	676.78	0	0	0	682.83	681.1	680.86	678.52	677.66	676.03	678.36
1986	680.94	677.1	0	0	0	683.6	685.25	685.07	680.13	679.42	678.72	680.41
1987	675.35	675.38	0	0	0	677.46	676.23	675.58	675.58	675.56	675.32	675.33
1988	675.34	675.44	0	0	0	676.97	676.39	675.39	675.18	675.27	675.39	675.41
1989	675.3	675.31	0	0	0	678.97	679	676.99	675.59	675.19	675.25	675.34
1990	675.55	675.12	0	0	0	675.8	675.37	676.72	678.44	676.38	676.12	675.33
1991	675.53	676.97	0	0	0	680.42	678.88	680.92	681.07	679.07	676.37	677.72
1992	675.54	675.38	0	0	0	679.81	679.19	677.08	676.04	678.02	675.44	675.53
1993	676.11	676.09	0	0	0	678.95	682.17	681.42	682.91	684.53	680.95	678.31
1994	0	0	0	0	0	680.26	680.75	681.08	677.49	677.96	676.16	676.4

Year	1-day min	3-day min	7-day min	30-day min	90-day min	1-day max	3-day max	7-day max	30-day max	90-day max	Zero days	Base flow
1972	675.23	675.27	675.28	675.69	675.54	686.48	686.35	685.61	682.35	680.37	0	1
1973	674.95	675.03	675.06	675.27	675.38	681.85	681.4	680.9	678.9	678.12	0	1
1974	674.84	674.95	675.02	675.24	675.32	683.36	683.21	682.74	680.41	679.63	0	1
1975	674.97	675.05	675.1	675.28	675.29	687.27	687.22	687.14	684.8	681.52	0	1
1976	675.07	675.08	675.06	675.13	675.17	684.72	684.68	684.32	680.6	677.16	0	1
1977	675.04	675.07	675.15	675.26	675.36	678.05	677.98	677.74	676.91	676.49	0	1
1978	674.8	674.88	675.08	675.36	675.45	683.36	683.32	683.15	681.48	678.86	0	1
1979	675.12	675.21	675.29	675.43	675.58	686.41	686.32	685.97	684.24	681.73	0	0.99
1980	675.1	675.19	675.26	675.22	675.18	680.15	680.1	679.94	678.46	676.9	0	1
1981	675.14	675.19	675.27	675.35	675.3	680.9	680.65	679.98	678.46	677.07	0	1
1982	675.13	675.27	675.37	675.46	675.7	685.3	685.25	684.9	683.38	680.68	0	1
1983	675.1	675.17	675.26	675.45	675.81	684.09	684.04	683.95	682.74	679.85	0	1
1984	675.05	675.13	675.24	675.45	675.76	685.55	685.5	685.3	683.77	682.27	0	0.99
1985	675.2	675.43	675.59	675.99	676.14	684.17	684.11	683.91	681.76	680.27	0	1
1986	676.19	676.25	676.51	676.26	675.72	687.5	687.4	687.09	685.46	683.57	0	0.99
1987	674.87	674.88	675.07	675.19	675.28	677.58	677.53	677.33	676.37	675.85	0	1
1988	674.66	674.82	675.03	675.13	675.26	677.78	677.58	677.49	676.51	675.68	0	1
1989	674.87	674.9	675	675.03	675.13	680.78	680.69	680.45	679.1	677.29	0	1
1990	674.67	674.75	674.93	675.01	675.08	679.91	679.88	679.78	678.79	677.18	0	1
1991	674.71	674.78	675.01	675.35	676.18	683.76	683.67	683.43	681.44	680.67	0	1
1992	674.91	674.96	675.02	675.31	675.32	682.37	682.31	682.02	679.4	677.55	0	1
1993	675.4	675.33	675.6	675.84	675.87	687.85	687.75	687.33	685.76	683.04	0	0.99
1994	675.26	675.29	675.48	675.79	676.81	684.03	683.98	683.83	682.42	679.85	0	1

Year	Date min	Date max	Lo pulses	Lo pulse dur	Hi pulses	Hi pulse dur	Rise rate	Fall rate	Reversals
1972	196	210	6	9.5	3	30.67	0.35	-0.19	46
1973	256	90	2	66.5	5	4.8	0.21	-0.19	70
1974	197	166	3	49.33	3	17.67	0.21	-0.17	62
1975	219	121	3	42	2	36	0.24	-0.21	62
1976	334	96	1	212	1	0	0.09	-0.13	87
1977	124	290	6	4.17	0	0	0.14	-0.13	89
1978	327	103	5	16.6	2	25.5	0.27	-0.17	60
1979	288	116	1	40	3	28.67	0.22	-0.19	57
1980	147	103	5	37.2	1	12	0.14	-0.14	73
1981	236	171	13	9	2	6.5	0.21	-0.15	65
1982	212	112	2	42.5	4	19.75	0.25	-0.2	57
1983	274	113	7	11.29	2	37.5	0.19	-0.2	42
1984	234	169	3	23.67	3	18.33	0.33	-0.21	41
1985	329	121	4	5	7	12.57	0.28	-0.21	39
1986	321	97	0	0	7	11.57	0.32	-0.21	45
1987	130	92	3	67.33	0	0	0.14	-0.11	88
1988	145	100	2	110	0	0	0.1	-0.1	84
1989	325	102	2	92	2	7	0.13	-0.13	79
1990	109	173	8	14.5	1	13	0.17	-0.18	72
1991	247	132	2	28	5	19.8	0.3	-0.2	43
1992	273	119	5	26.8	3	8.33	0.15	-0.17	63
1993	334	180	4	7.75	1	163	0.24	-0.18	61
1994	255	125	3	9.33	1	0	0.21	-0.18	48

Appendix 4. Stillwater Gage Records Trend Analysis

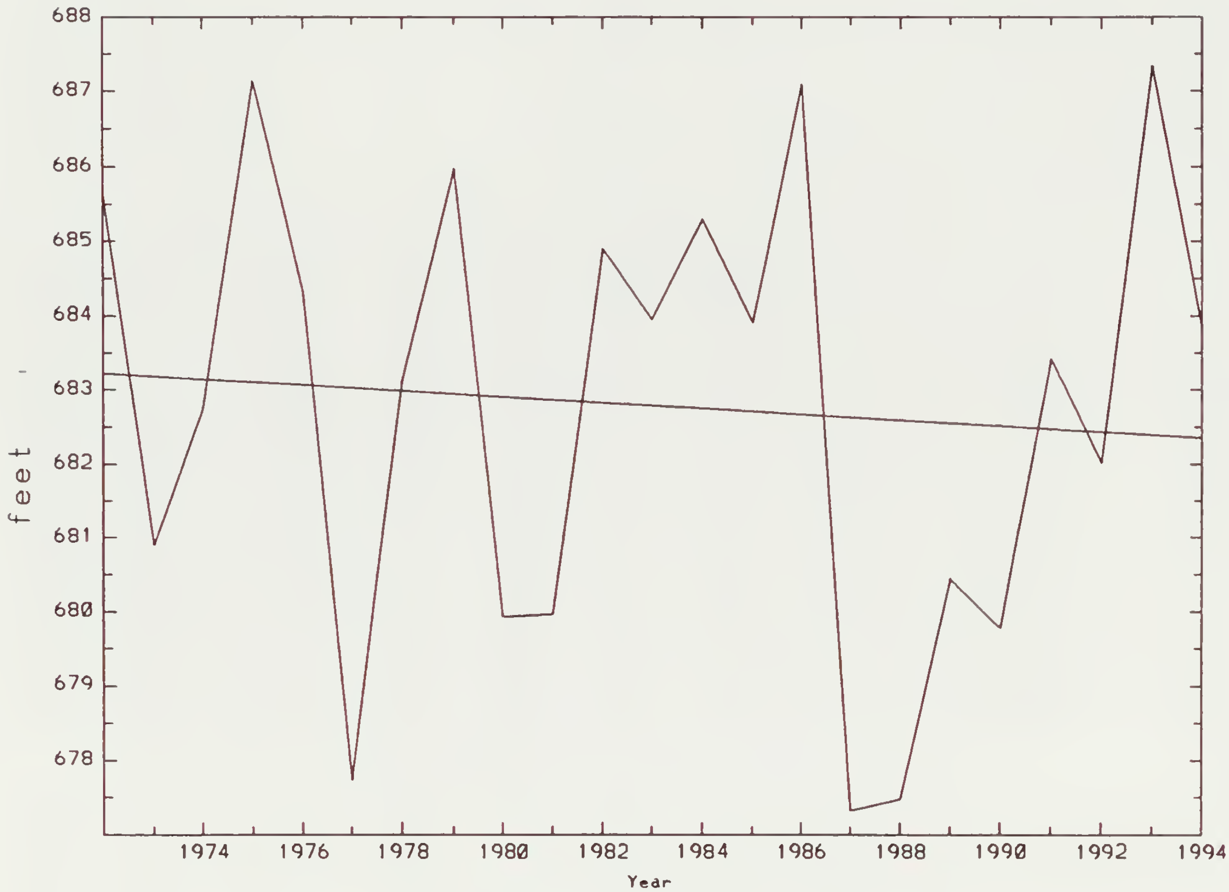
Stillwater Gage Trend Analysis
3-day maximum streamflow



Slope = -.507E-01 Y-intercept = .784E+03
Standard Error = .319E+01 R**2 = .012
F-statistic = .256E+00 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis

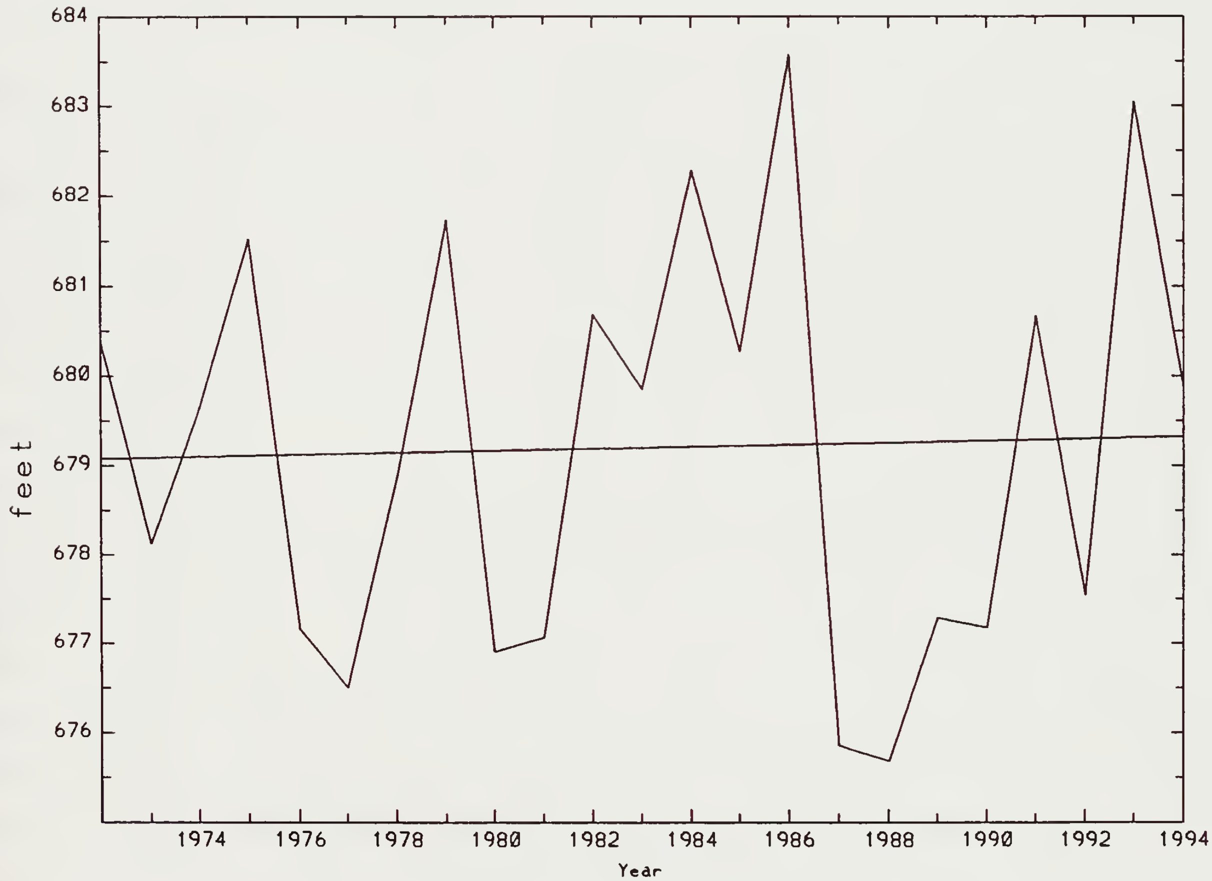
7-day maximum streamflow



Slope = -.396E-01 Y-intercept = .761E+03
Standard Error = .316E+01 R**2 = .008
F-statistic = .159E+00 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis

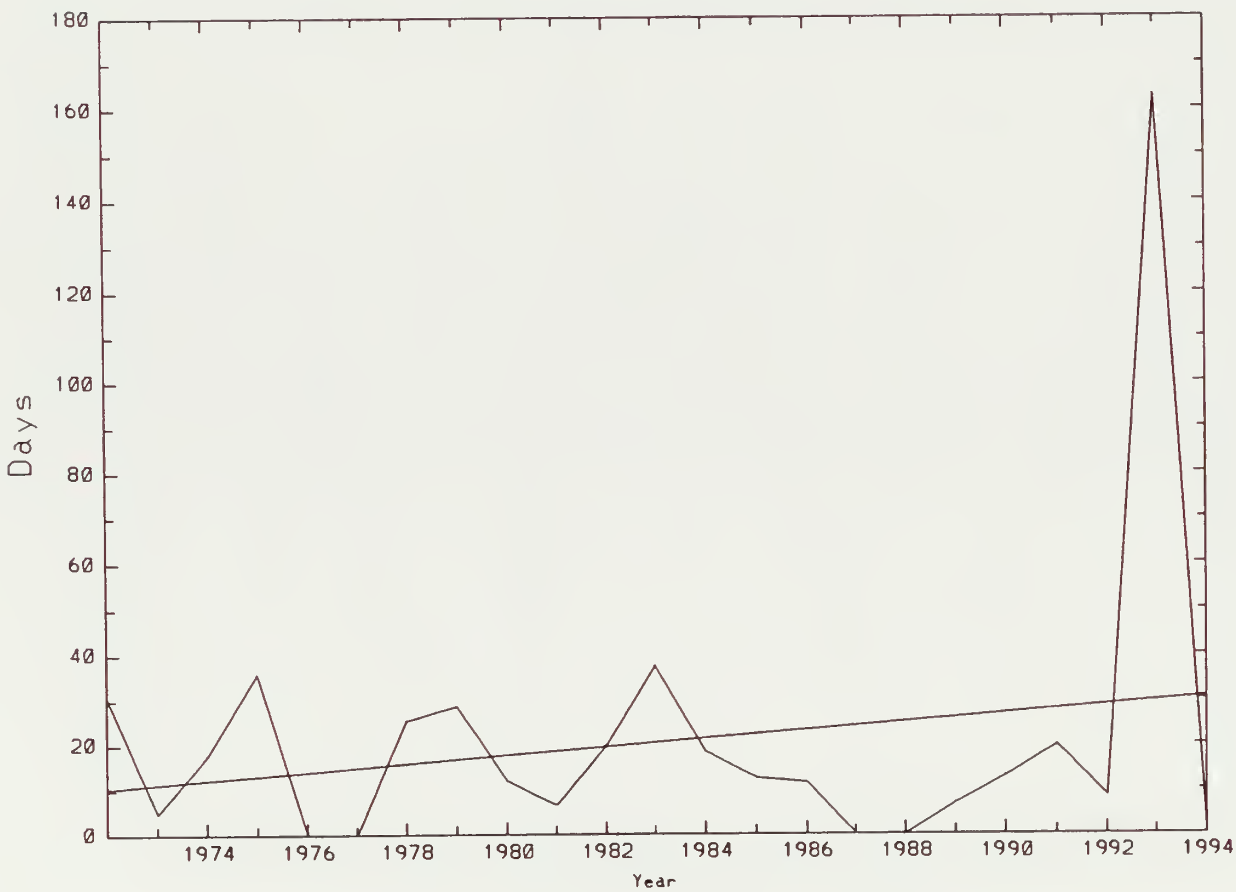
90-day maximum streamflow



Slope = .112E-01 Y-intercept = .657E+03
Standard Error = .238E+01 R**2 = .001
F-statistic = .223E-01 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis

Average length of high pulses

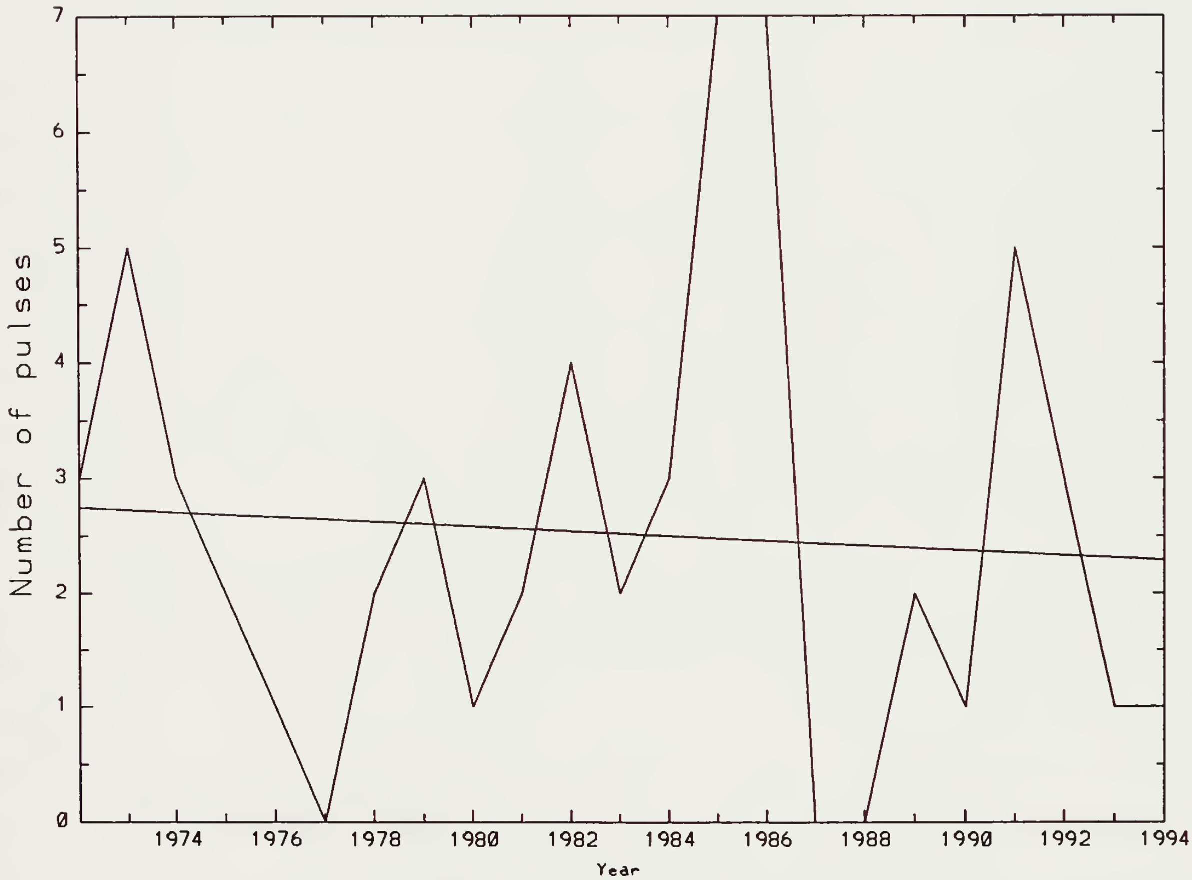


Slope = .920E+00 Y-intercept = -.180E+04

Standard Error = .333E+02 R**2 = .035

F-statistic = .771E+00 NOTE! P-value > 0.25

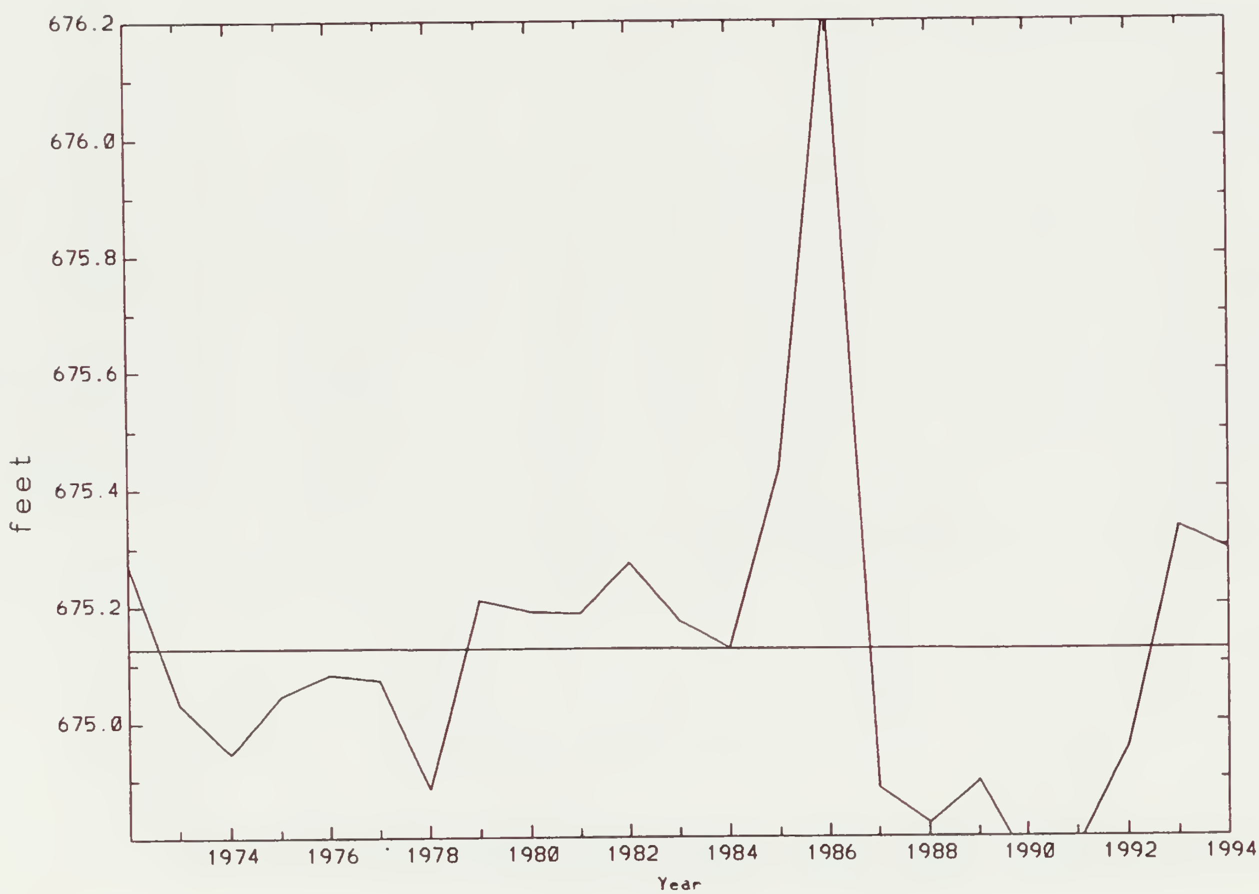
Stillwater Gage Trend Analysis
Annual number of high pulses



Slope = -.208E-01 Y-intercept = .437E+02
Standard Error = .204E+01 R**2 = .005
F-statistic = .105E+00 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis

3-day minimum streamflow



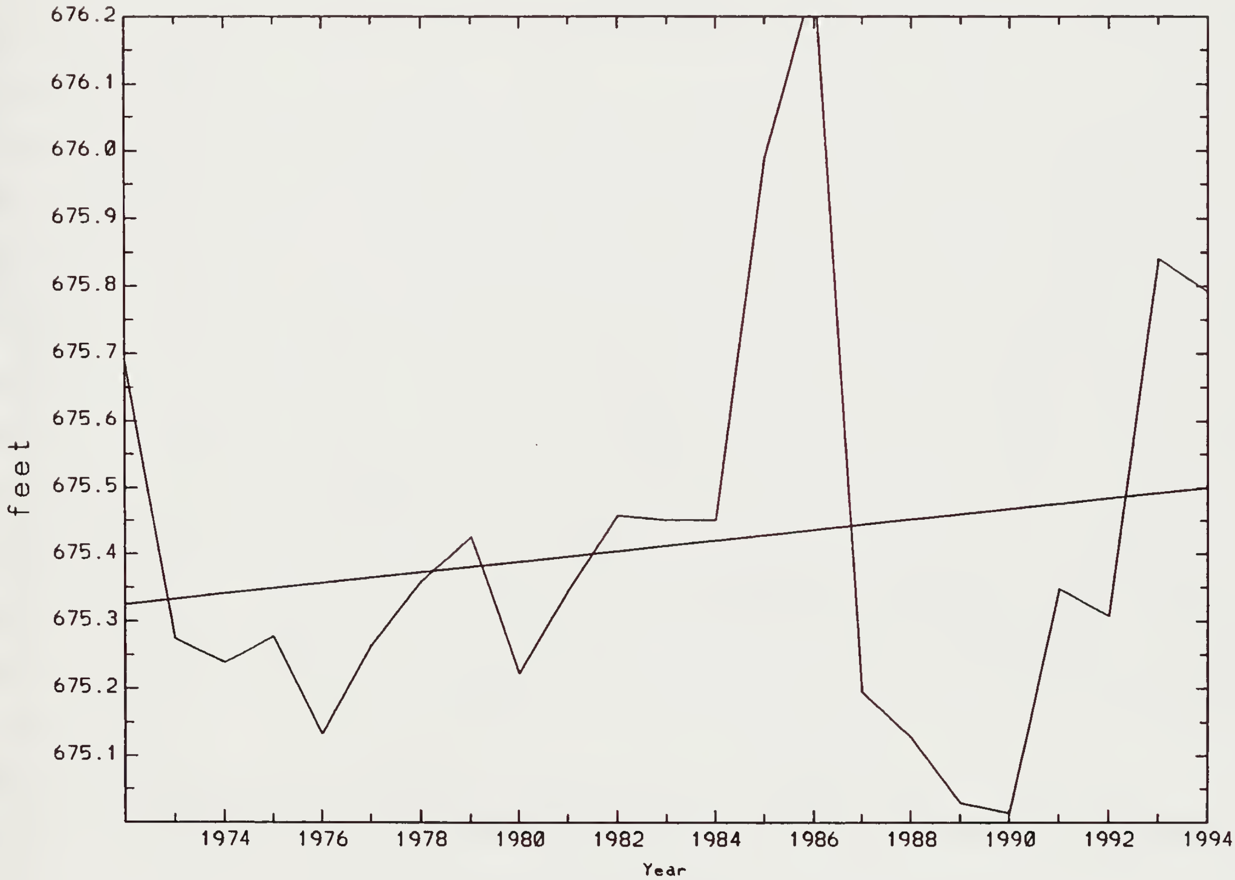
Slope = -.232E-03 Y-intercept = .676E+03

Standard Error = .315E+00 R**2 = .000

F-statistic = .546E-03 NOTE! P-value > 0.25

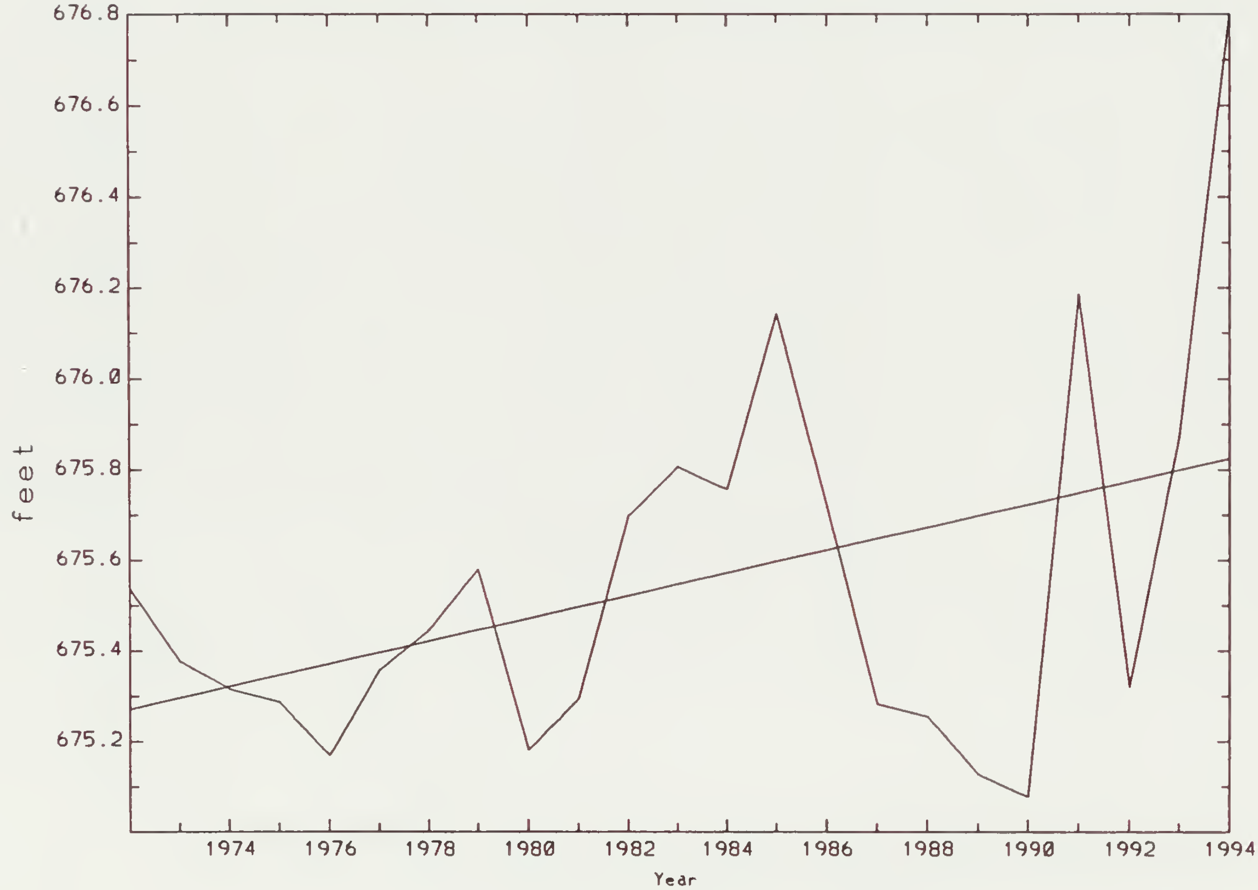
Stillwater Gage Trend Analysis

30-day minimum streamflow



Slope = .796E-02 Y-intercept = .660E+03
Standard Error = .313E+00 R**2 = .030
F-statistic = .657E+00 NOTE! P-value > 0.25

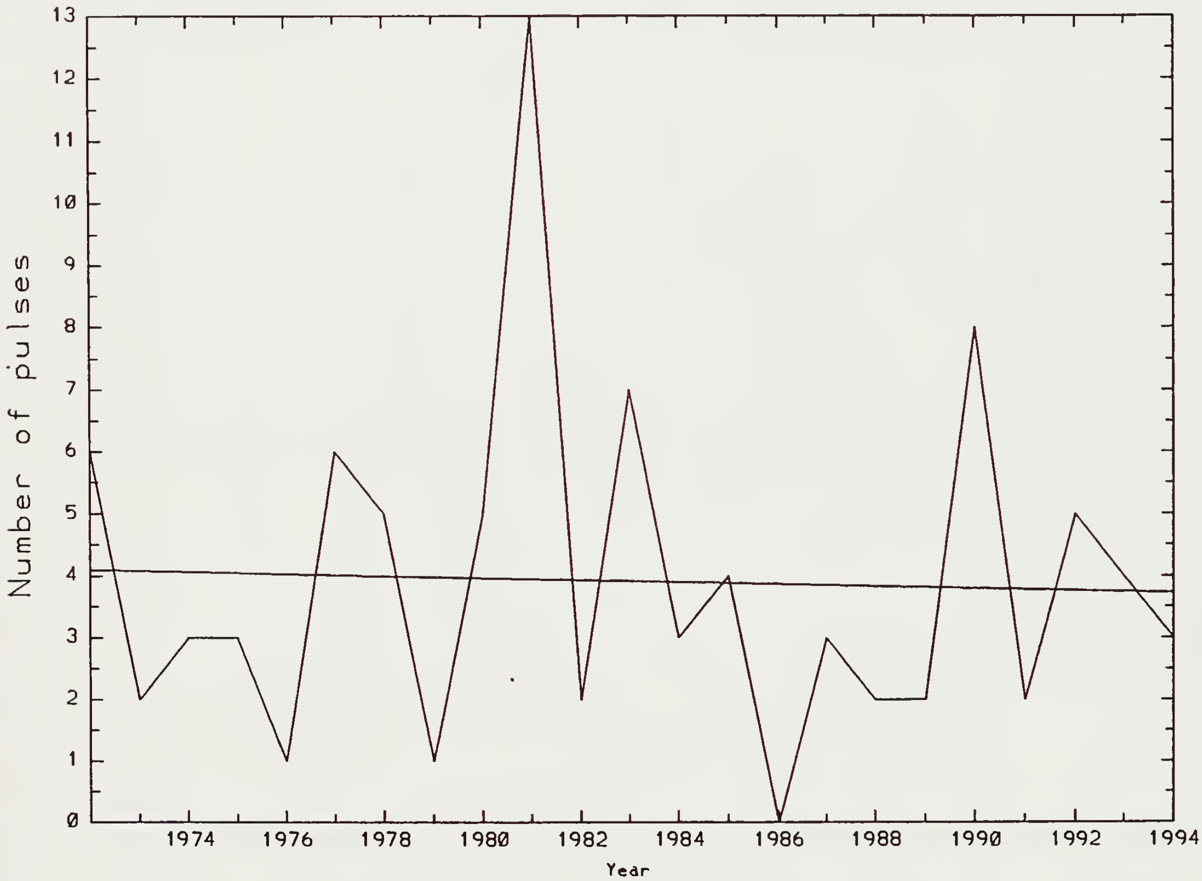
Stillwater Gage Trend Analysis
90-day minimum streamflow



Slope = .251E-01 Y-intercept = .626E+03
Standard Error = .387E+00 R**2 = .169
F-statistic = .428E+01 P-value < .050

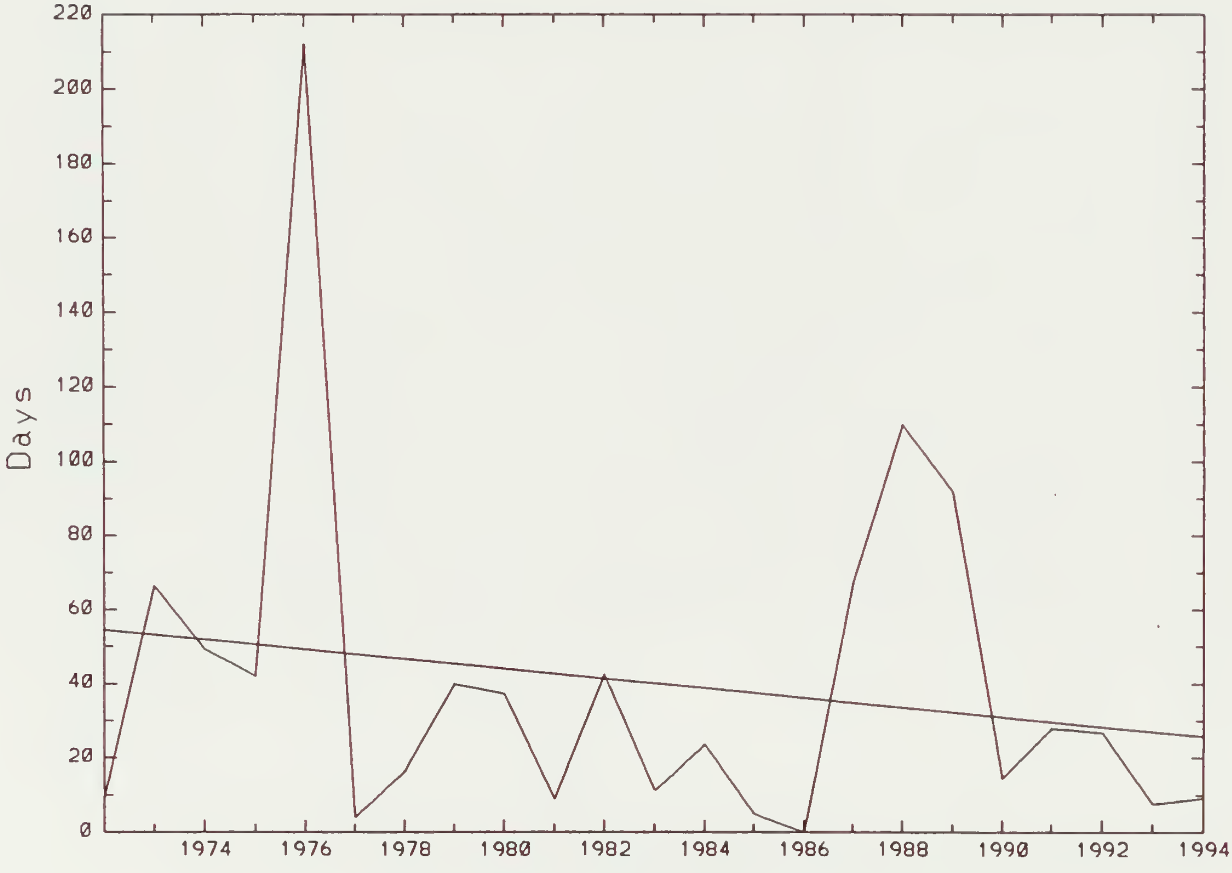
Stillwater Gage Trend Analysis

Annual number of low pulses



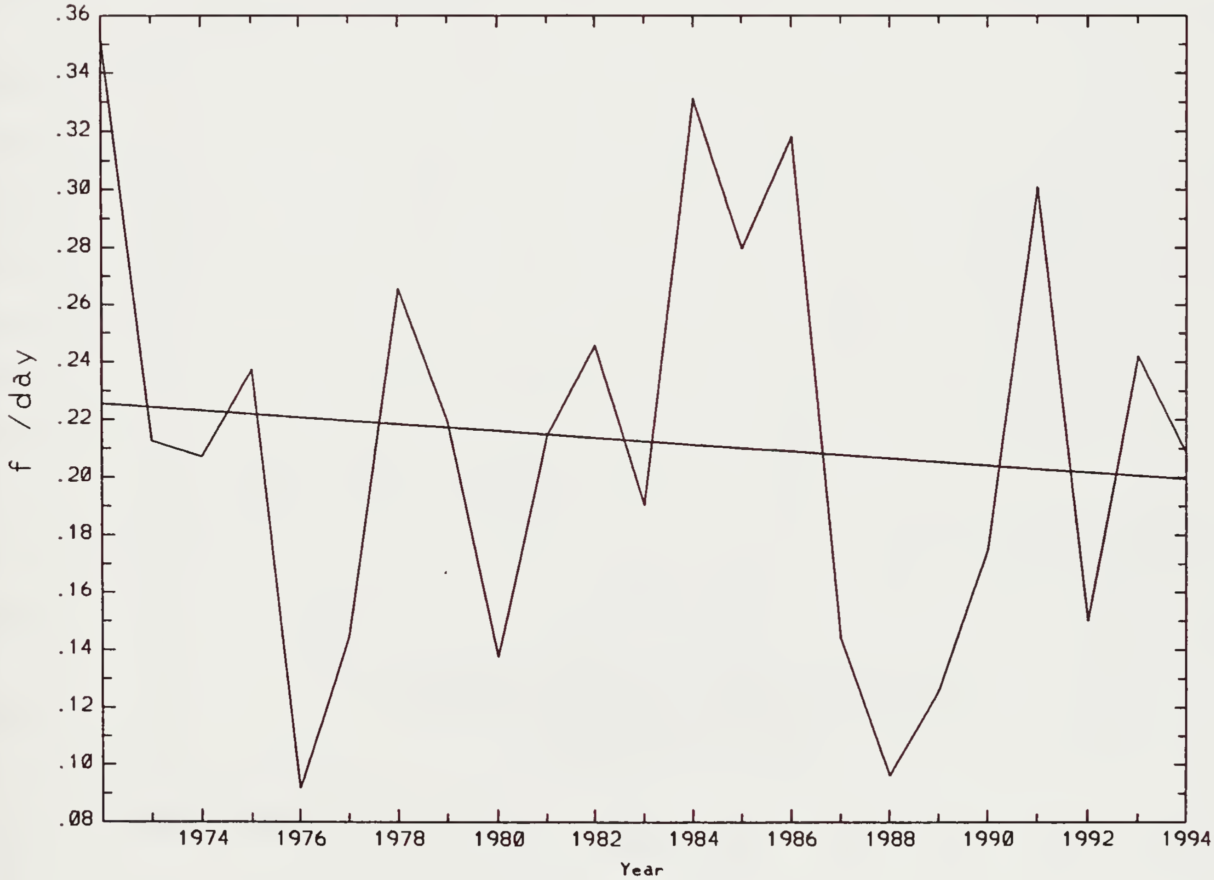
Slope = -.168E-01 Y-intercept = .372E+02
Standard Error = .289E+01 R**2 = .002
F-statistic = .342E-01 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis
Average length of low pulses



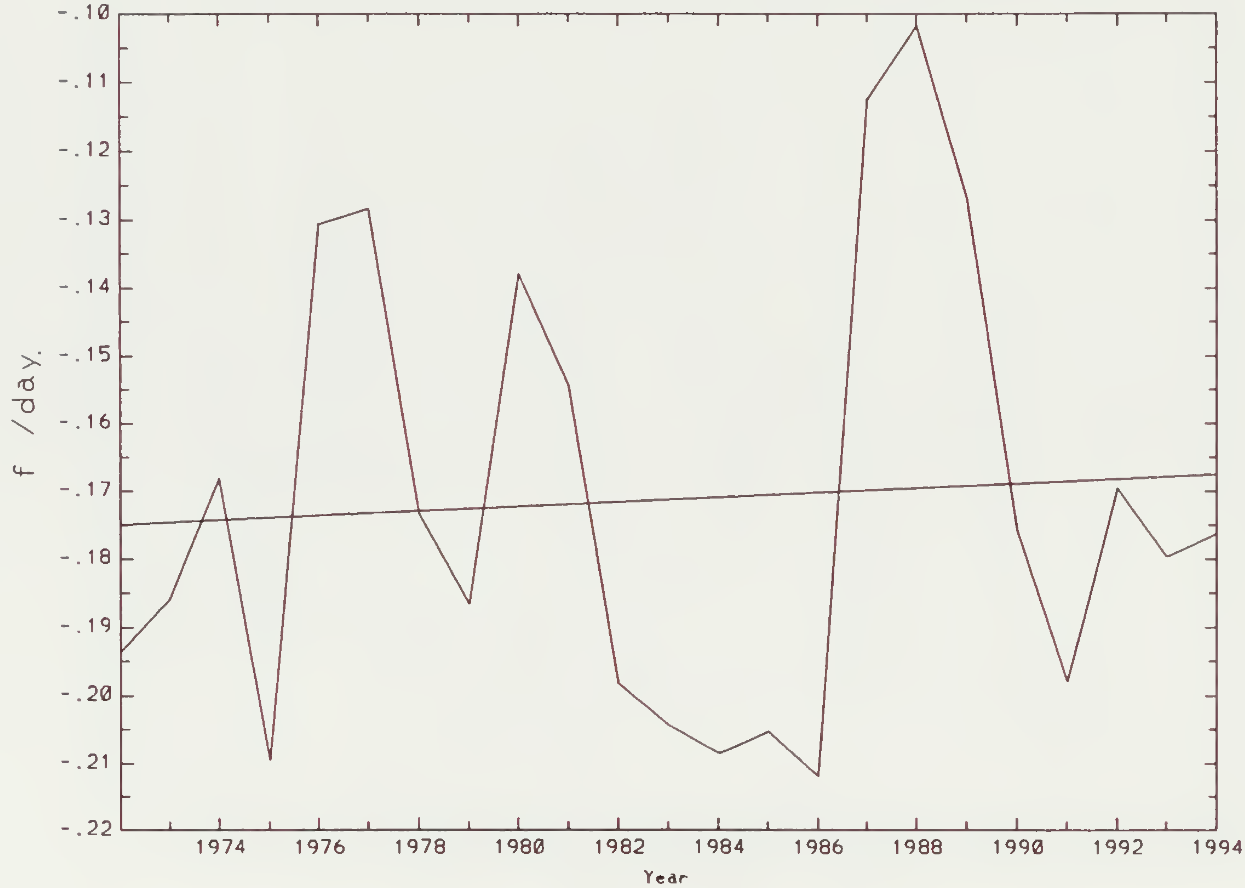
Slope = -.131E+01 Y-intercept = .263E+04
Standard Error = .476E+02 R**2 = .035
F-statistic = .762E+00 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis
Average rate of hydrographic rise



Slope = -.118E-02 Y-intercept = .256E+01
Standard Error = .747E-01 R**2 = .012
F-statistic = .254E+00 NOTE! P-value > 0.25

Stillwater Gage Trend Analysis
Average rate of hydrographic fall



Slope = .340E-03 Y-intercept = -.844E+00
Standard Error = .340E-01 R**2 = .005
F-statistic = .101E+00 NOTE! P-value > 0.25

ST. CROIX RIVER RECREATIONAL BOATING STUDIES

CHAPTER 10

ST. CROIX ISLAND VEGETATION STUDY

Submitted by

Deborah Konkel
Wisconsin Department of Natural Resources
West Central Region
Eau Claire, Wisconsin

March, 1999

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INTRODUCTION

A study of the vegetation on islands in the Lower St. Croix River was conducted September 24, 1996, September 16, 1997 and September 21, 1998 by Water Resources staff of the Western District - Wisconsin Department of Natural Resources (DNR).

A study of the vegetation was conducted as part of a larger study of the impacts of boating on the St. Croix River. The vegetation at sites within four usage classes was compared: 1) Boating and Trampling 2) Boats Only 3) Trampling Only 4) No Boats or Trampling.

The main concern that this vegetation study was to address was the impact that river and island use was having on the vegetation of the islands, because the vegetation of the islands is critical to the island and river ecosystems.

A healthy plant community plays a vital role within an ecosystem. This is due to the role plants play in 1) improving water quality 2) providing valuable resources for fish and wildlife 3) resisting invasions of non-native species 4) stabilizing shorelines and slopes and 5) checking excessive growth of tolerant species that could crowd out the more sensitive species, therefore reducing the diversity.

1) Plant communities improve water quality in many ways: they trap nutrients, debris, and pollutants entering the water; they reduce erosion by damping wave action and stabilizing shorelines; they can shade the near-shore area for part of the day.

2) Plant communities provide important fishery and wildlife resources. Plants start the food chain that supports all levels of wildlife, and at the same time produce oxygen needed by animals. Plants are used as food, cover and nesting sites by a variety of wildlife. Diversity in the plant community creates more microhabitats for more species.

Changes in island vegetation could potentially impact the long-term morphology and viability of the islands.

METHODS

Field Methods

In order to study the impacts of recreation on the St. Croix River Islands, study sites were selected to represent different levels of recreational use and placed within one of the four usage classes:

1) Boats Only - This usage classification refers to areas in which there are no restrictions on wave size and therefore the waves generated by recreation boats impact the shoreline.
2) Trampling Only - This usage classification indicates that the site experiences significant foot traffic which results in the trampling of plants.
3) Boats & Trampling - This usage classification refers to sites that experience impacts from both the waves and the foot traffic.
4) No Boats or Trampling - this usage classification refers to sites that are not impacted by either waves or foot traffic.

The 1996 study sites were selected by the Interagency Island Study Team. The placement of individual sites into usage classifications was based on collective personal experience and professional judgement of the study team. Pins were buried in the soil at each site, for the purpose of relocating each site with a metal detector for the various types of studies being conducted (Appendix I).

A transect, perpendicular to the shoreline and running inland, was oriented from each site pin. Two additional transects, parallel to the first transect, were oriented on either side at a random distance, using a random numbers table. Within each transect, vegetation was recorded at the shoreline and every meter inland from the shore. At each meter, the species rooted within a 0.25 m^2 quadrant were recorded. The percentage of each species and/or bare soil along the transect line was visually estimated.

The 1997 study sites were randomly selected by river mile using a computerized random number generator (Appendix II). Each study site was categorized into one of the four usage classes based on the best professional judgment of the researchers. One transect, perpendicular to the shoreline was oriented at each site on the map. At the shoreline and every meter inland from the shore, a 0.25 m^2 quadrant was placed. The percent bare soil was recorded within each transect. The percent coverage of bare soil was the only factor recorded in 1997, since bare soil coverage was the only factor analyzed in 1996 that was significantly different between the different usage classes.

The 1998 study sites were randomly selected from 750 sites that had data on boat use. Sixty sites were randomly selected, but only 59 could be surveyed (Appendix III). From the randomly selected sites that were surveyed, there were 12 sites with data indicating no boat use or trampling, 16 sites with data indicating impact from both boats and trampling, 16 sites with data indicating impacts form trampling only and 15 sites with data indicating impacts from boats only. At the shoreline and every one meter inland from the shore, a 0.25 m^2 quadrant was placed. The percent bare soil was recorded within each transect.

<u>Data Analysis</u>

The transects were analyzed separately by their usage classification:
1) "Boats & Trampling"
2) "Boats only"
3) "Trampling only"
4) "No boats or Trampling".

The 1996 study sites were analyzed by comparing the difference in mean percent coverage of exotics, annuals, perennials and bare soil between the classes of sites at each distance from the shore. The comparison was made using paired t-test to determine if statistically significant differences existed between the quadrants in each usage class.

The 1997 and 1998 study sites were analyzed separately by comparing the difference in mean percent coverage of bare soil between the classes of sites at each distance from the shore. The comparison was made using paired t-test to determine if statistically significant differences existed between the quadrants in each usage class.

RESULTS - 1996

Species Present

Thirty species were found at the transects. Of this total, 3 were exotic species, 8 were annual species, and 19 were perennial species (Table 1). No endangered or threatened species were found. One species of Special Concern was found: *Cardamine pratensis*.

Table 1. Plant Species

Scientific Name	Common Name
Exotic Species	
1) *Bromus inermis* Leyss.	smooth brome
2) *Digitaria ischaemum* (Schreb.) Muhl.	crabgrass
3) *Taraxacum officinale* Weber.	common dandelion
Annual Species	
4) *Bidens connata* Muhl.	swamp beggarticks
5) *Cyperus erythrorhizos* Muhl.	sedge
6) *Cyperus rivularis* Kunth.	sedge
7) *Echinochloa walteri* (Pursh) Nash.	wild millet
8) *Eleocharis intermedia* (Muhl.) Schultes.	spike rush
9) *Lindernia dubia* (L.) Pennell.	false pimpernel
10) *Panicum capillare* L.	panic grass
11) *Polygonum lapathifolium* L.	smartweed
Perennial Species	
12) *Acer saccharinum* L.	silver maple
13) *Alnus crispa* (Ait.) Pursh.	green alder
14) *Aster laterifolius* (L.) Britton.	calico aster
15) *Aster simplex* Willd.	panicled aster
16) *Boehmeria cylindrica* (L.) Sw.	false nettle
17) *Boltonia asteroides* (L.) L'Her.	boltonia
18) *Cardamine pratensis* L.	cuckooflower
19) *Carex comosa* Boott.	sedge
20) *Carex tuckermani* Boott.	sedge
21) *Cyperus strigosus* L.	sedge
22) *Fraxinus nigra* Marsh.	black ash
23) *Leersia oryzoides* (L.) Swartz.	rice cut-grass
24) *Ludwigia palustris* (L.) Ell.	false loosestrife
25) *Mentha* sp.	mint
26) *Panicum* sp.	panic grass
27) *Phalaris arundinacea* L.	reed canary grass
28) *Sagittaria* sp.	arrowhead
29) *Salix* sp.	willow
30) *Spartina pectinata* Link.	cord grass

Dominant Vegetation

"Boats and trampling" sites were overwhelmingly dominated by bare soil. "Boats only" and "trampling only" sites also had bare soil as a dominant cover (Figure 1).

Sedge (*Carex comosa*) was the dominant plant; *Leersia oryzoides* and *Lindernia dubia* were common species in the "boats only" and "trampling only" sites. Sedge was more dominant in the "boats only" sites than in the "trampling only" sites.

"No boats or trampling" sites had the lowest dominance of bare soil. Although, sedge was also the dominant species at these site, there were more species that were common as compared to the other three usage classifications.

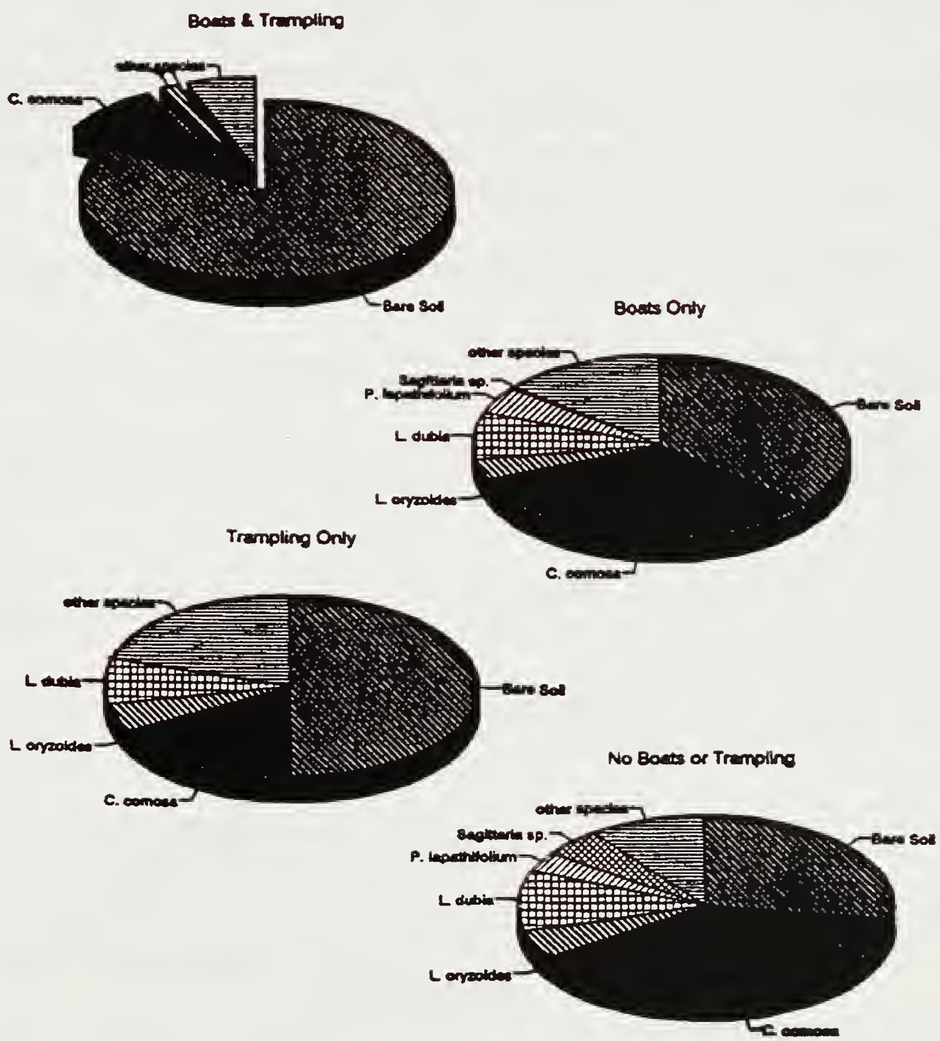


Figure 1. Dominant vegetation at transect types

Change with Distance from the Shore

All discussions relating to significant differences are statitistically significant differences.

Bare soil

The "boats & trampling" transects had the greatest amount of bare soil at all distances from the shore (Figure 2). Within the "boats & trampling" transects, there was not a significant change in the amount of bare soil with increased distance from the shore.

"No boats or trampling" transects had the smallest amount of bare soil except at the shore. The decrease in the amount of bare soil decreased significantly as the distance from the shore increased. The amount of bare soil was significantly less at all other distances from the shore than at the shore ($p<0.01$). There was significantly less bare soil at 3, 4 and 5-meters from shore than one-meter from shore ($p<0.01$) and two-meters from the shore ($p<0.05$).

Intermediate levels of bare soil were found at the "boats only" and "trampling only" transects. The amount of bare soil declined with the distance from the shore. "Boats only" transects had significantly less bare soil at 3-meters than at the shore ($p<0.05$). "Trampling only" transects had significantly less bare soil at 4 and 5-meters from the shore than at the shore.

Comparing the different types of transects, "boats & trampling" transects had significantly greater

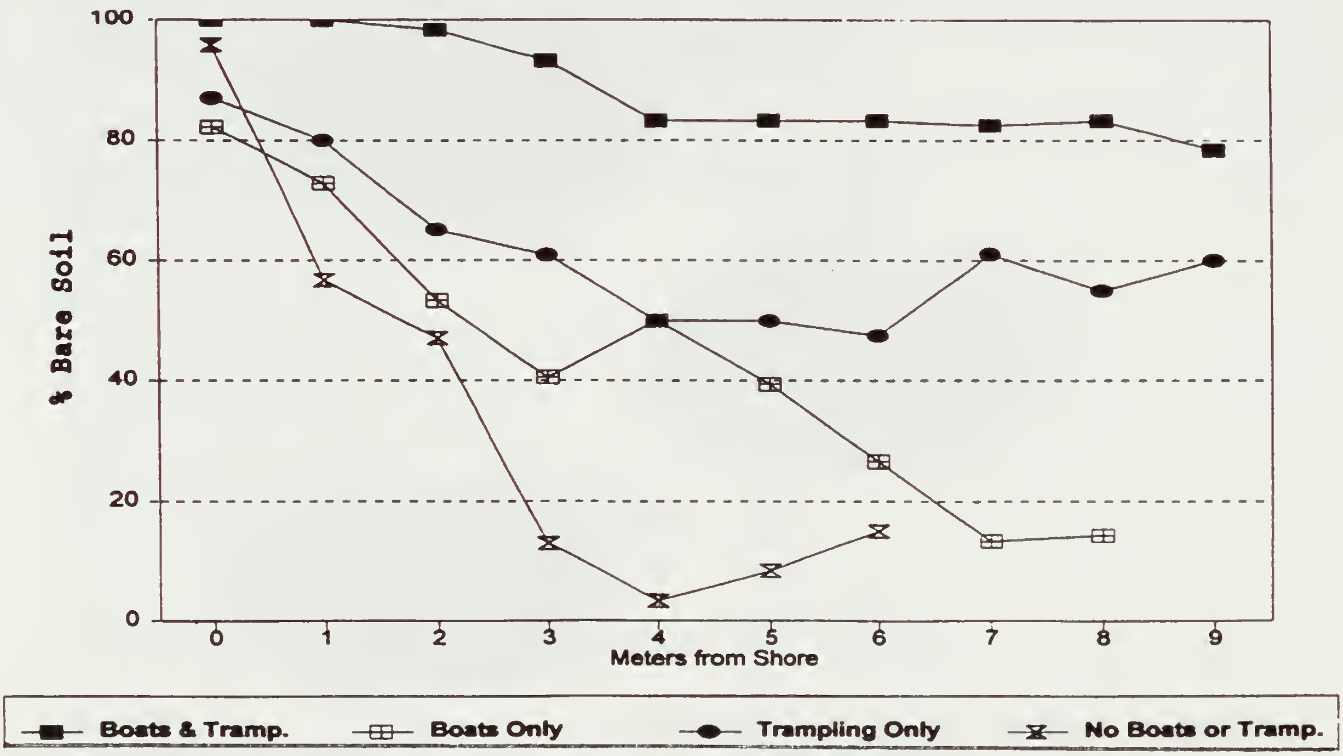


Figure 2. Mean percent of bare soil within transect types, 1996

amounts of bare soil than "no boats or trampling" transects at 1-meter ($p<0.01$), 2-meters ($p<0.05$) and 3, 4 and 5-meters ($p<0.01$). "Boats & trampling" also had significantly more bare soil than "trampling only" at 2 and 3-meters ($p<0.05$ and $p<0.01$). "Boats & trampling" transects had significantly more bare soil than "boats only transects" at 2 and 3-meters ($p<0.05$). "Trampling only" transects had significantly more bare soil than "no boats or trampling" transects at 3, 4 and 5-meters ($p<0.01$). "Boats only" transects had significantly more bare soil than "no boats or trampling" transects at 4-meters.

Perennial vegetation

Coverage of perennial vegetation was sparse at the shore, but increased with increasing distance from the shore (Figure 3).

"No boats or trampling" transects had the greatest increase in perennial coverage with distance from the shore. There was significantly more perennial coverage at 1 and 2-meters than at the shore ($p<0.05$) and at 3, 4 and 5-meters than at the shore ($p<0.01$). There was significantly more perennial coverage at 3, 4 and 5-meters than at 1-meter from the shore ($p<0.01$) and 2-meters from the shore ($p<0.05$).

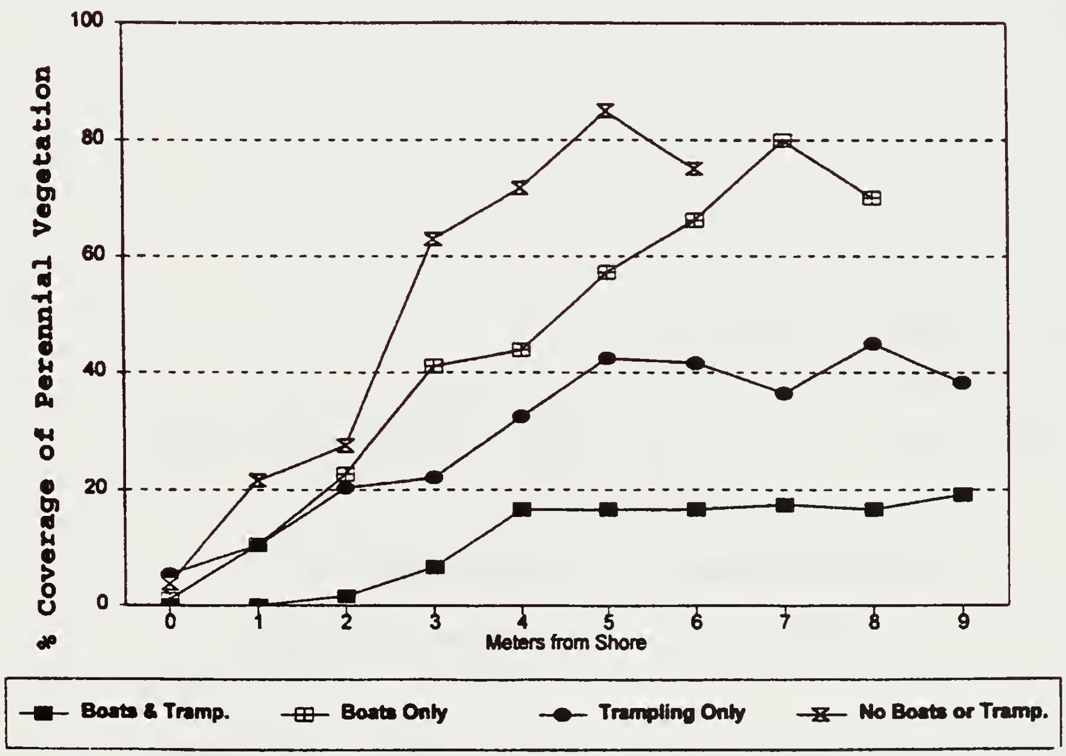


Figure 3. Mean percent coverage of perennial vegetation within transect types, 1996

"Boats & trampling" transects had the lowest coverage of perennial vegetation and there was no significant difference in perennial coverage at different distances from the shore (Figure 4).

"Boats only" transects and "trampling only" transects had intermediate coverage of and increase in perennial vegetation. "Boats only" transects had significantly more perennial coverage at 2, 3, 4 and 5-meters from the shore than at the shore ($p<0.05$, $p<0.01$, $p<0.05$, $p<0.01$). There was also significantly greater coverage at 3 and 5-meters than at 1-meter ($p<0.05$). "Trampling only" transects had significantly greater coverage at 4 and 5-meters from the shore than at the shore ($p<0.05$, $p<0.01$) and at 5-meters than at 1-meter from the shore ($p<0.05$).

Comparing the different types of transects, "no boats or trampling" transects had significantly greater perennial coverage than "boats & trampling" transects at 1, 3, 4 and 5-meters from the shore ($p<0.05$, $p<0.01$, $p<0.05$, $p<0.01$). "No boats or trampling" had significantly greater perennial coverage than "trampling only" transects at 3, 4 and 5-meters ($p<0.05$).

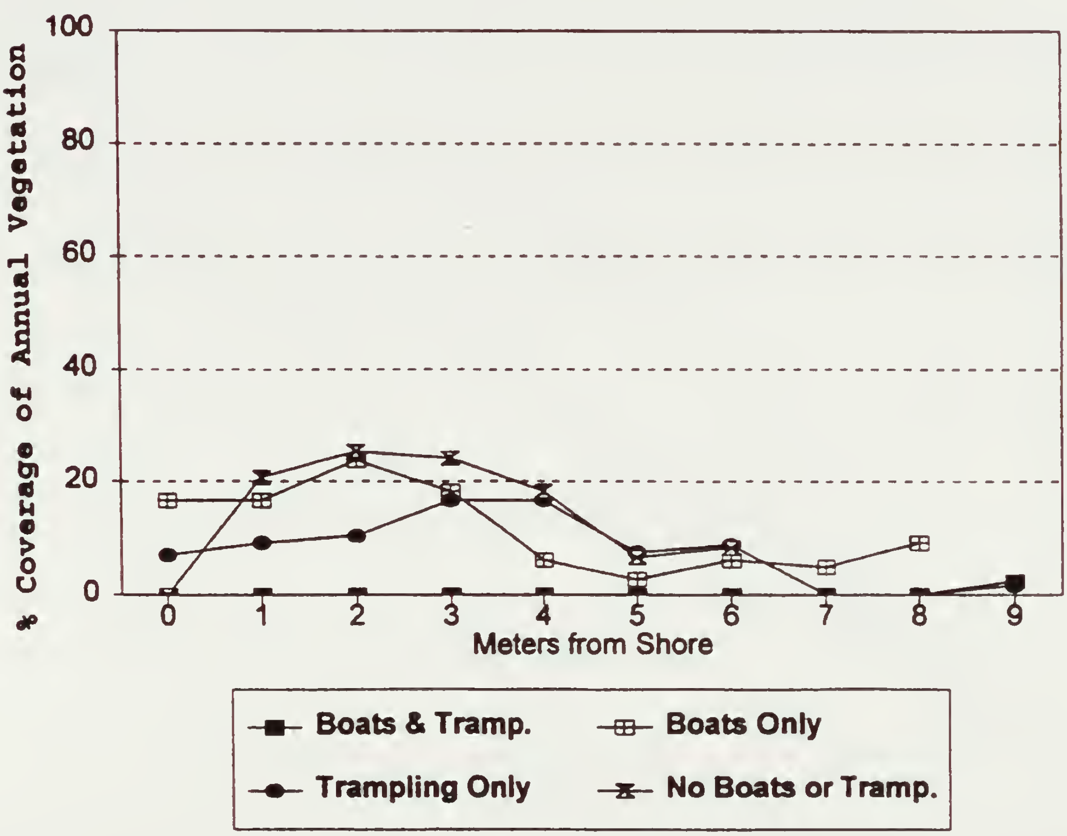


Figure 4. Mean percent coverage of annual vegetation within transect types, 1996.

Annual vegetation

Coverage by annual vegetation was moderate (Figure 4). "No boats or trampling" transects had the highest overall coverage of annuals. This coverage was highest at 1-4-meters, especially at 2-meters. There was significantly greater coverage by annuals at one-meter than at the shore ($p<0.05$) and at 2, 3 and 4-meters than at the shore ($p<0.01$).

There was no significant difference in annual coverage between the transect types.

Non-native vegetation

Very little non-native vegetation was found at any of the study sites. Low levels of non-natives were found at the "trampling only" sites, at 3-meters and 6-meters from the shore (Figure 5).

RESULTS - 1997

Because bare soil was the only cover type that showed any significant trend, the 1997 study was set up to compare only the difference in the amount of bare soil at each site. When the randomly selected sites (Figure 6) were categorized at the time of the site visit: there were 9 "boats & trampling" transects, 14 "boats only" transects, 2 "trampling only" transects and 15 "no boats or trampling" transects.

Change in Bare Soil with Distance from the Shore

Among transects

The "boats & trampling" transects had the greatest amount of bare soil at all distances from the shore (Figure 8) except the shore, 1-meter, 2-meter and 4-meter sites of the "trampling only" transects. The "boats & trampling" transects and the "trampling only" transects had 100% bare soil at the shore, 1-meter and 2-meter sites. The "trampling only" transects had more bare soil at

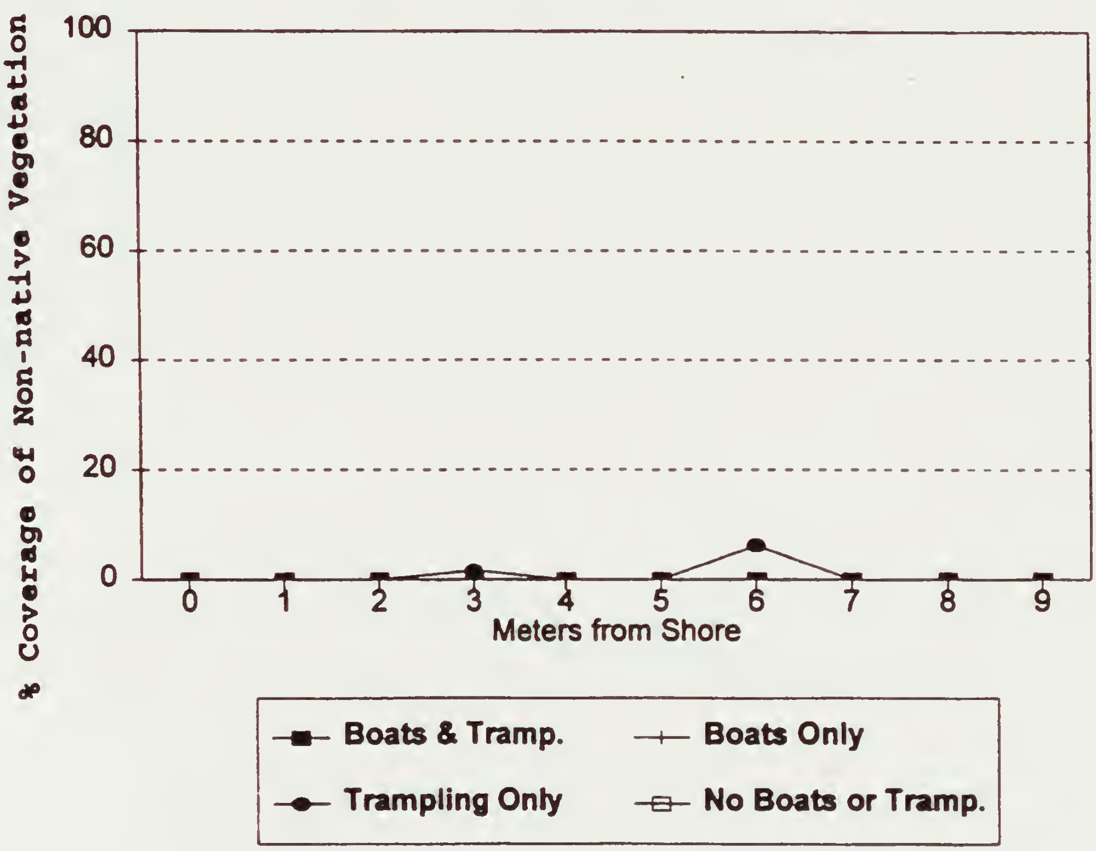


Figure 5. Mean percent coverage of non-native vegetation within transect types, 1996

the 4-meter sites. However, it would be inappropriate to draw firm conclusions with the "trampling only" transects due to the fact that there were only two transects in this category. The higher mean coverage of bare soil at the "boats & trampling" transects was significantly higher is some cases. It was significantly higher than the "boats only" transects at the shore and 1-meter ($p<0.05$), 2-meter ($p<0.01$) and 6 meter ($p<0.05$).

The higher mean coverage of bare soil at the "boats & trampling" transects was significantly higher than the "no boats or trampling" transects at 1-meter, 2-meter, 3-meter, 4-meter, 5-meter, 6-meter, 7-meter and 8-meter ($p<0.01$).

The "trampling only" transects had significantly more bare soil than the "no boats or trampling" transects at 2-meter and 3-meter ($p<0.05$) and 4-meter ($p<0.01$).

Within Transects

Within the "boats & trampling" transects, although the amount of bare soil decreased with increased distance from the shore, there was not a significant decrease until 7 meters from the

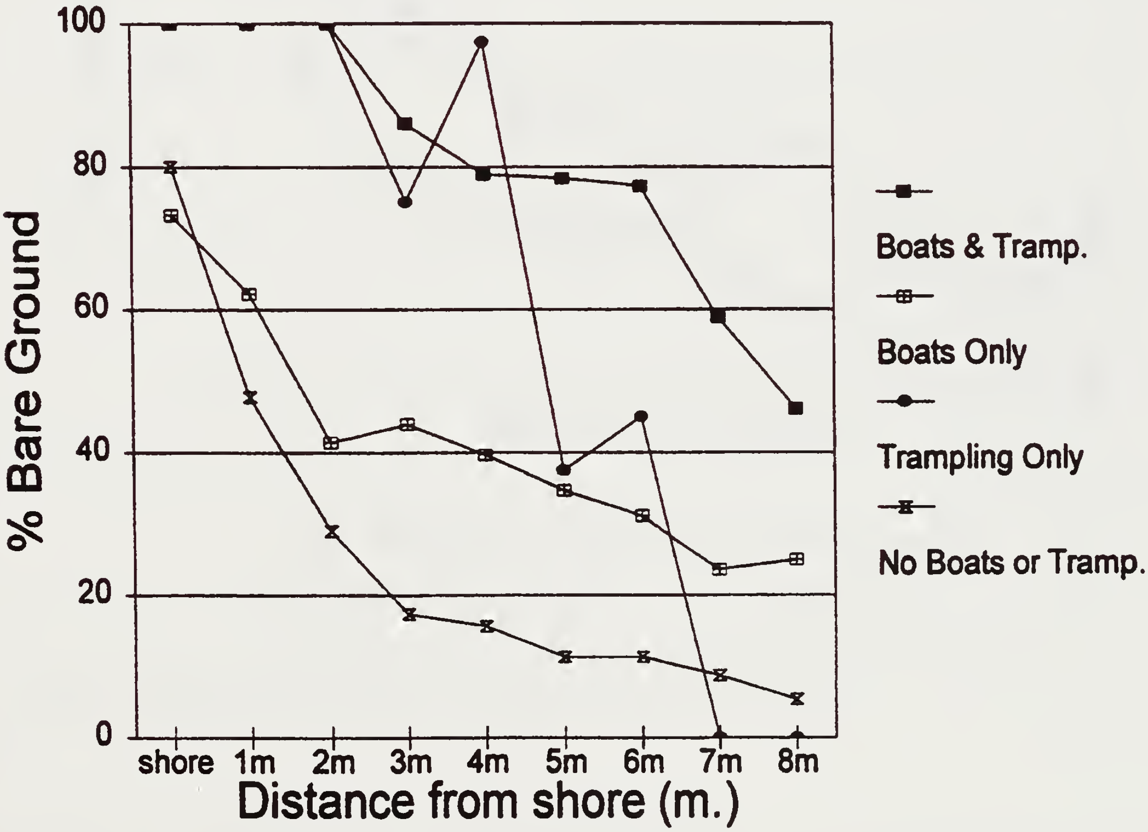


Figure 6. Mean percent of bare soil within transect types, 1997

shore ($p<0.05$). The area from the shore to 2 meters back remained 100% bare.

"Boats only" transects did not show a significant decrease in bare soil up to 5 meters, but the largest decline in bare soil occurred at 2 meters from the shore and this transect had lower levels of bare soil.

There were not enough sample sites in the "trampling only" transects to show statistical significance

"No boats or trampling" transects had the smallest amount of bare soil except at the shore. The amount of bare soil decreased significantly as the distance from the shore increased. The amount of bare soil was significantly less at all other distances from the shore than at the shore ($p<0.01$). There was significantly less bare soil at 3, 4, 5 and 6 meters from shore than one-meter from shore ($p<0.05$).

RESULTS - 1998

Again, bare soil was the only cover type that was recorded in the 1998 study. The intend of the 1998 study was to compare the difference in the amount of bare soil at each usage class.

Among transects

All transect types experienced a high mean coverage of bare soil at the shore. However, the mean coverage of bare soil at the "trampling only" and "no boats or trampling" transects decreased more rapidly with distance from the shore than at the "boats & trampling" and "boats only" transects (Figure 7).

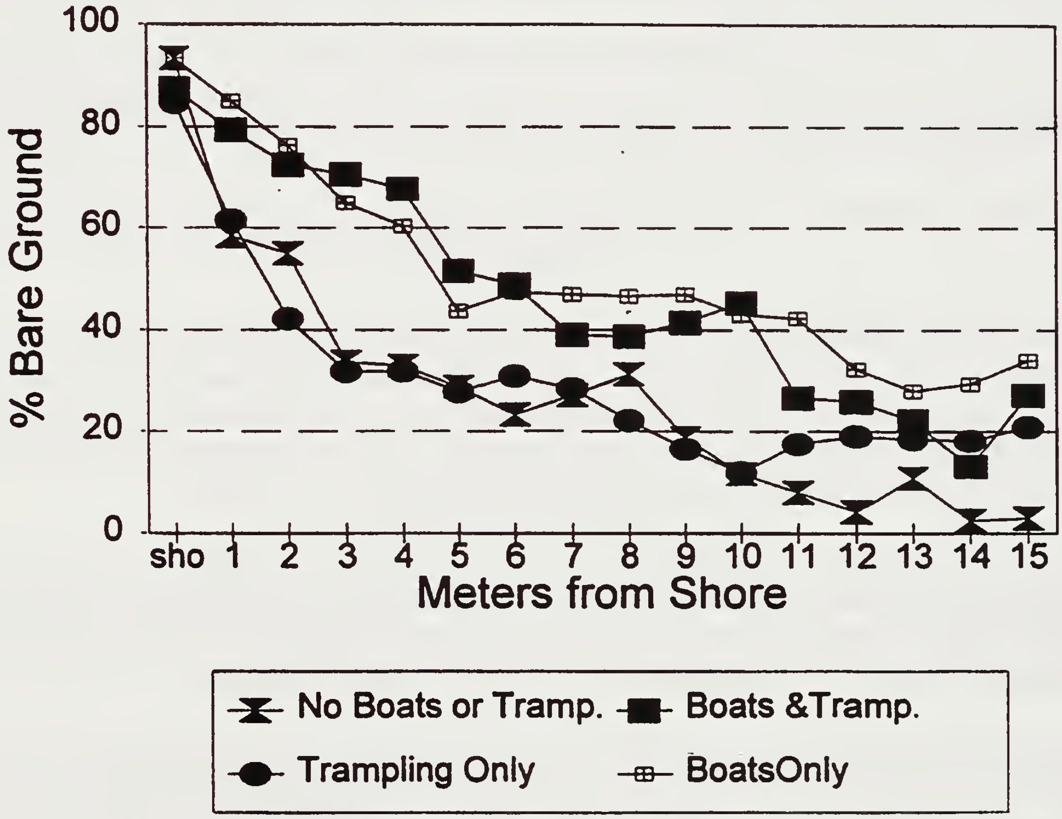


Figure 7. Mean percent of bare soil within transect types, 1998

The higher mean coverage of bare soil at the "boats & trampling" transects was significantly higher is some cases. The coverage of bare soil was significantly higher than the "no boats or trampling" and the "trampling only" transects at 3 and 4 meters from the shore ($p<0.05$).

Within Transects

Within the "boats & trampling" transects, although the amount of bare soil decreased with increased distance from the shore, there was not a significant decrease until 5 meters from the shore ($p<0.05$). The amount of bare soil continued to drop significantly at each meter from 6 meters to 9 meters from the shore ($p<0.05$). In addition, the sites 5 and 6 meters from the shore had significantly less bare soil than 1 and 2 meters from the shore.

"Boats only" transects did not show a significant decrease in bare soil until 4 meters from the shore ($p<0.05$). The coverage of bare soil continued to be significantly less than the bare soil at the shore at 5-9 meters from the shore ($p<0.01$). The coverage of bare soil was also significantly less at the 5-9 meter distance from shore as 1 and 2 meters from the soil also.

The "trampling only" transects had a statistically significance decrease in bare soil starting at 2 meters from the shore ($p<0.01$).

The bare soil at the "no boats or trampling" transects started decreasing significantly at 1 meter from the shore ($p<0.01$).

DISCUSSION

In 1996, sites within the "boats & trampling" usage class had the greatest amount of bare soil and the lowest coverage of perennial vegetation. Bare soil dominated these sites. The amount of bare soil was significantly greater and the amount of perennial vegetation was significantly less than the amount of bare soil and perennial vegetation at sites in "no boats or trampling" transects. These differences were significant at almost all distances from the shore.

The sites with "boats & trampling" had more bare soil than "boats only" or "trampling only". The differences were significant at some distances. In addition, the amount of bare soil did not decrease significantly nor did the amount of perennial vegetation increase significantly with increasing distance from the shore at sites with boat use and trampling.

Sites without boat use or trampling had the lowest level of bare soil and the greatest coverage of perennial vegetation. The amount of bare soil decreased significantly at nearly each meter from the shore. The amount of perennial vegetation increased significantly at nearly every two meters from the shore. These sites also had the highest coverage of annual vegetation.

Sites with either trampling or boat use had intermediate levels of bare soil and perennial vegetation. The amount of bare soil decreased and perennial vegetation increased with increasing distance from shore. Low levels of non-native vegetation were found at the sites with trampling only. This is probably due to exotic seeds that have been brought in on the shoes of persons using the island.

In 1997, the study of bare soil at randomly selected sites confirmed the findings during 1996.

In 1997, the study of bare soil at randomly selected sites confirmed the findings during 1996. Mean coverage of bare soil was highest at "boats & trampling" transects and lowest at "no boats or trampling" transects.

In addition, the amount of bare soil at "boats & trampling" transects did not decrease significantly until 7 meters from the shore. The amount of bare soil at "no boats or trampling" transects decreased significantly at 3 meters from the shore.

In 1998, the study again confirmed the previous findings. "Boats & trampling" transects and "boats only" transects had higher levels of bare soil, significantly higher at some distances.

All usage classes had high levels of bare soil, but the difference was in how far bare soil extended back from the shore.
1) The transects in the "no boats or trampling" usage class experienced significant decreases in bare soil at 1-meter from the shore.
2) The "trampling only" transects exhibited significant decreases in bare soil starting at 2-meters from the shore.
3) The "boats only" transects did not show significant decreases in bare soil until 4-meters from the shore.
4) The "boats & trampling" transects, however, did not show significant decreases in bare soil until 5-meters from the shore.

CONCLUSIONS

Boat use and foot traffic at the St. Croix River Islands may be negatively impacting the island vegetation and increasing the amount of bare soil. This makes the islands more prone to erosion and the river more likely to move sediment downstream and negatively impact aquatic habitats.

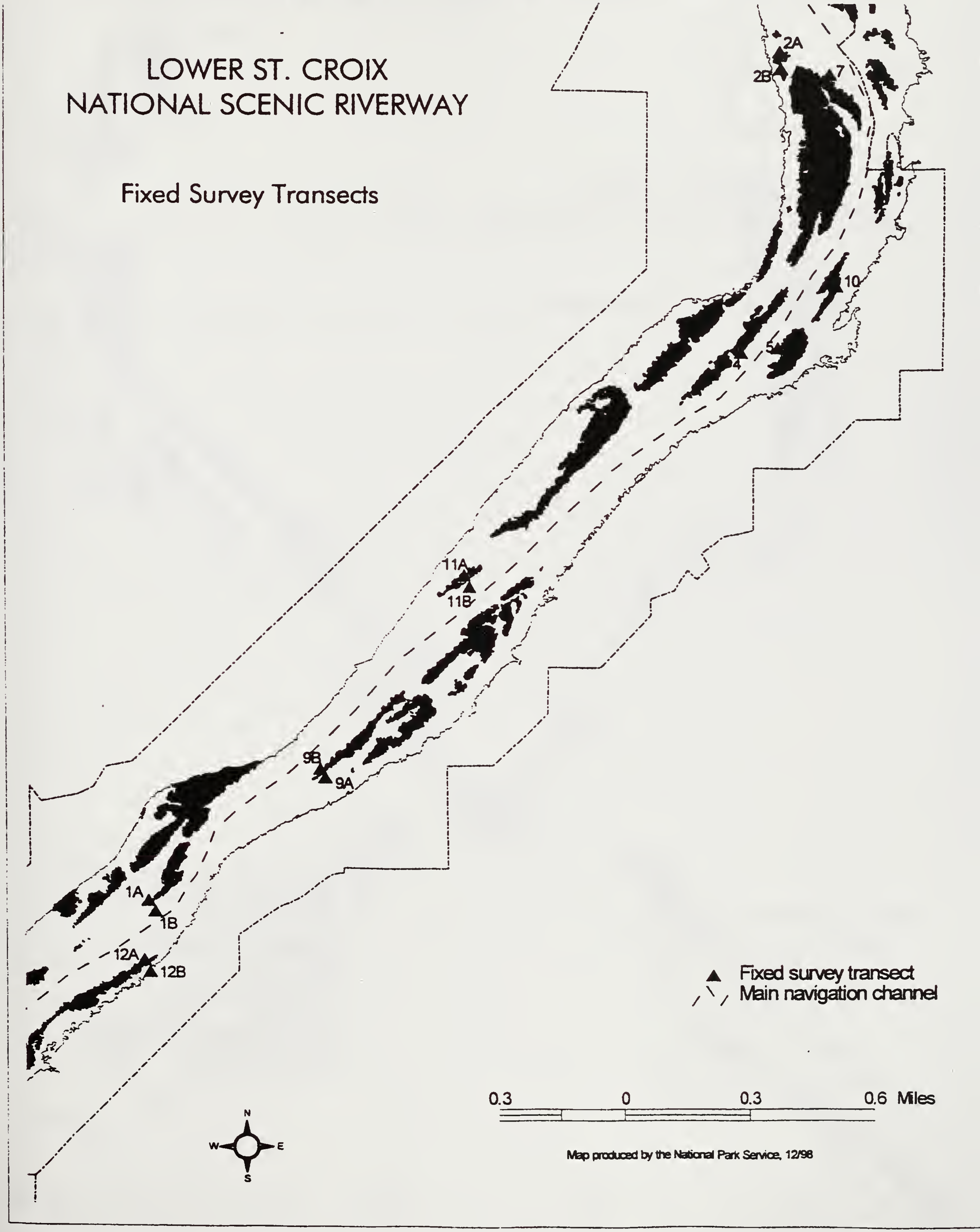
The evidence for this impact is the increase in bare soil and decrease in vegetation with higher levels of usage. Islands without any evidence of boat or trampling use have the highest coverage of perennial vegetation and the lowest amount of bare soil.

Islands that have both boat use and trampling have the highest level of bare soil and the lowest coverage of perennial vegetation.

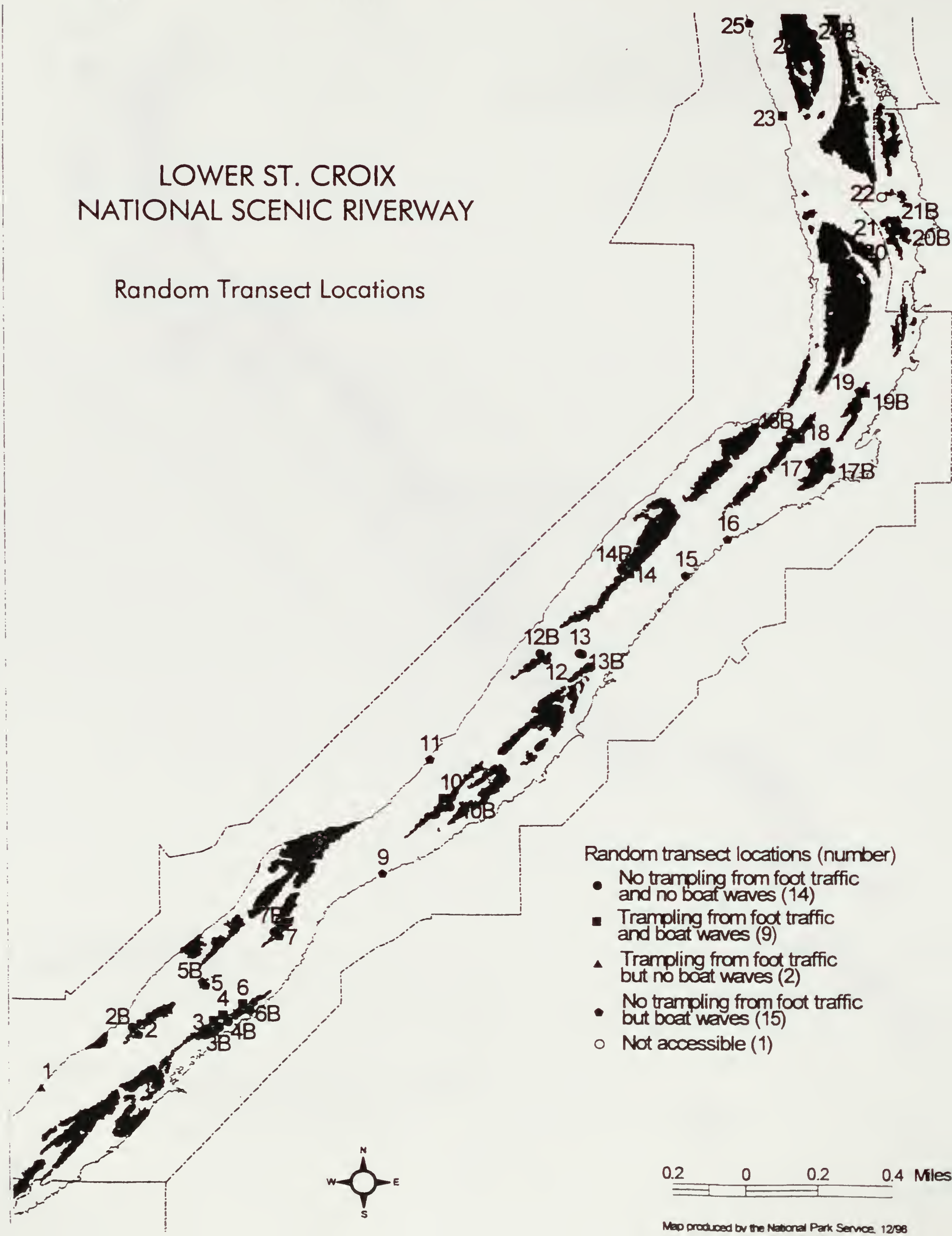
The impact to the vegetation, as measured by significant decrease in bare soil with distance from the shore, is felt further inland as the usage of the islands increase.

APPENDICES

Appendix I. Fixed Survey Transects for Shoreline Erosion Study
1996 Vegetation Study Sites



Appendix II. 1997 Vegetation Survey Sites Selected Randomly by River Mile



Appendix III. 1998 Vegetation Survey Sites Randomly Selected from Sites with Boating Use Data